Hypertension

AHA SCIENTIFIC STATEMENT

Ambulatory Blood Pressure Monitoring in Children and Adolescents: 2022 Update: A Scientific Statement From the American Heart Association

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ABSTRACT: Use of ambulatory blood pressure monitoring in children and adolescents has markedly increased since publication of the last American Heart Association scientific statement on pediatric ambulatory blood pressure monitoring in 2014. In addition, there has also been significant expansion of the evidence base for use of ambulatory blood pressure monitoring in the pediatric population, including new data linking ambulatory blood pressure levels with the development of blood pressure–related target organ damage. Last, additional data have recently been published that enable simplification of the classification of pediatric ambulatory monitoring studies. This scientific statement presents a succinct review of this new evidence, guidance on optimal application of ambulatory blood pressure monitoring in the clinical setting, and an updated classification scheme for the interpretation of ambulatory blood pressure monitoring in children and adolescents. We also highlight areas of uncertainty where additional research is needed.

Key Words: AHA Scientific Statements ■ adolescent ■ blood pressure monitoring, ambulatory ■ child ■ hypertension

Substantial data link blood pressure (BP) levels in youth with adult hypertension[1] and subclinical target organ damage (TOD).[2] Epidemiological studies have demonstrated associations between clinic BP or diagnosed hypertension in youth and atherosclerotic cardiovascular disease and premature mortality.[3] However, ambulatory BP (ABP), that is, multiple BP readings obtained over an entire 24-hour period, is better able to distinguish true BP status and, in comparison with clinic BP, is a better predictor of TOD in adults and is a better target for therapeutic goals in high-risk pediatric populations.[4] Therefore, the American Academy of Pediatrics (AAP) 2017 "Clinical Practice Guideline for Screening and Management of High Blood Pressure in Children and Adolescents" recommends ambulatory blood pressure monitoring (ABPM) in all children suspected to have hypertension on the basis of clinic BP measurements to confirm the diagnosis of hypertension.[5] On the basis of substantial new data linking ABPM levels to TOD in youth, this scientific statement provides updated guidance on the application and interpretation of ABPM in pediatric patients.

In addition to an expanded role for ABPM in the diagnosis and management of pediatric hypertension, the 2017 AAP clinical practice guideline (CPG) includes new normative pediatric BP tables based on normal-weight children and revised BP definitions that incorporate static cut points for adolescents ≥13 years.[5] The latter align with updated adult hypertension guidelines issued in 2017 by the American Heart Association (AHA) and American College of Cardiology (ACC).[6] Application of these new normative BP values and definitions to National Health and Nutrition Examination Survey 1999 to 2014 data results in 5.8% of youth being reclassified

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Table 1. Revised Classification for Ambulatory Blood Pressure Studies in Pediatric Patients

	Clinic systolic or diastolic blood pressure*		Mean ambulatory systolic or diastolic blood pressure	
Category	<13 y of age	≥13 y of age	<13 y of age	≥13 y of age
Normal blood pressure	<95th percentile	<130/80	<95th percentile OR adolescent cut points*	<125/75 mm Hg 24-h AND <130/80 mm Hg wake AND <110/65 mm Hg sleep
WCH	≥95th percentile	≥130/80		
Masked hypertension	<95th percentile	<130/80	≥95th percentile OR adolescent cut points*	≥125/75 mm Hg 24-h OR ≥130/80 mm Hg wake OR ≥110/65 mm Hg sleep
Ambulatory hypertension	≥95th percentile	≥130/80		

*Including 24 h, wake, and sleep blood pressure. WCH indicates white coat hypertension.

into a higher BP stage.[7] Use of the new criteria is also associated with more sensitive identification of youth with additional risk factors for atherosclerotic cardiovascular disease, such as elevated body mass index, dyslipidemia, prediabetes, and with BP-related TOD.[8]

CARDIOVASCULAR RISK IN THE PEDIATRIC POPULATION

Preservation of ideal cardiovascular health is essential for the prevention of acquired heart disease during adulthood. Cardiovascular disease (CVD)–related risk factors, including elevated BP and hypertension, develop in childhood and track into adulthood.[1] Childhood hypertension remains a major risk factor for the development of acquired heart disease in adulthood, amplifying the importance of early diagnosis and treatment. Among those who develop stage 1 and stage 2 hypertension before 40 years of age, incident rates of CVD are 3.15 and 8.04 per 1000 person-years, respectively.[9] It is notable that the prevalence of adult CVD decreases from 49.2% to 9.3% when excluding hypertension.[9] Identifying and treating childhood hypertension, therefore, has the potential to have a substantial effect on the prevention of adult CVD.

BP and Risk for TOD

Elevated childhood BP is associated with TOD during youth and adulthood. Extensive literature relates elevated BP to adverse changes in carotid intima-media thickness (cIMT), pulse wave velocity, left ventricular hypertrophy (LVH), and neurocognition.[10] Individuals with persistently elevated BP during childhood and adulthood have a greater relative risk for higher cIMT[11] and pulse wave velocity[12] as adults than those with normal BP. Adults with a history of elevated childhood BP that later normalizes do not have a significant increase in cIMT as adults,[11] supporting the importance of treating pediatric hypertension to decrease future risk. Alterations in cIMT, pulse wave velocity, LVH, and neurocognition also occur during childhood and are associated with ABPM-diagnosed elevated BP.[13]

Recent data also support the concept that extended exposure to elevated BP is associated with short- and long-term intermediate outcomes, including LVH and impaired neurocognition.[14,15] Both LVH[2] and changes in left ventricular systolic and diastolic function[16] occur in children at BP levels below current thresholds for the diagnosis of hypertension. Last, longitudinal studies have shown that the long-term burden of elevated systolic BP (SBP)[15] during adolescence is associated with adult LVH.

USEFULNESS OF ABPM TO CLASSIFY BP

The major advantages of ABPM are to mitigate spuriously elevated BP from measurement anxiety (ie, white coat hypertension [WCH]), and to assess circadian BP patterns. Classification of patients into different BP phenotypes (Table 1) helps to stratify risk and guide therapy. When clinic BP and ABP are both normal, the patient is considered normotensive. When the opposite is true, the patient has ambulatory hypertension. When the BP as measured by the 2 techniques differs, the patient has either WCH or masked hypertension.

White Coat Hypertension

WCH is diagnosed when the clinic BP is in the hypertensive range, but ABP is normal (Table 1). The reported prevalence of WCH at referral centers among children referred for evaluation of elevated clinic BP varies widely but is common.[17] Available data indicate that children with WCH have left ventricular mass and other preclinical markers of CVD that are higher than in normotensive patients but lower than in those with ambulatory hypertension.[17] Despite some studies showing that WCH may not be a stable BP phenotype,[18] treatment and follow-up patterns vary widely between centers, highlighting the need for prospective studies of youth with WCH.

Masked Hypertension

Masked hypertension is diagnosed when the clinic BP is normal but ABP is elevated. Masked hypertension may be diagnosed on the basis of several scenarios, including isolated elevated wake BP, isolated elevated sleep BP (nocturnal hypertension), or the combination. We believe that isolated blunted nocturnal BP dipping (see Nocturnal Hypertension section) in the absence of elevated mean BP, in general, is not considered a form of masked hypertension.

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Table 2. Clinical Conditions and Other Settings Where Ambulatory Blood Pressure Monitoring Should Be Strongly Considered

Condition	Rationale for ambulatory blood pressure monitoring
Clinic hypertension	Confirmation of diagnosis
Secondary hypertension	Identify masked hypertension including nocturnal hypertension, abnormal dipping
Chronic kidney disease	Identify masked hypertension including nocturnal hypertension; assess mean arterial pressure and blood pressure targets to optimize therapy, slow disease progression, and reverse total organ damage
Coarctation of the aorta	Detect recurrent/masked hypertension years after primary repair
Types 1 and 2 diabetes	Identify abnormal circadian variation; optimize therapy to prevent/treat microalbuminuria and vascular changes
Obesity	Identify masked hypertension including nocturnal hypertension (which may signal comorbid obstructive sleep apnea) and abnormal dipping; optimize therapy to reverse total organ damage
Obstructive sleep apnea	Characterize hypertension severity, identify nocturnal hypertension or abnormal dipping
Genetic syndromes	Identify abnormal blood pressure patterns suggesting secondary cause of hypertension, such as renal artery stenosis and aortic coarctation
Neurofibromatosis type 1	
Turner syndrome	
Williams syndrome	
Antihypertensive drug treatment	Assess adequacy of blood pressure control and apparent treatment resistance, evaluate hypotensive symptoms
Research	Reduce sample size requirements for clinical trials; identify specific ambulatory blood pressure monitoring patterns associated with elevated cardiovascular risk

Relatively few studies are available estimating the prevalence of masked hypertension in the general pediatric population. One recent study described a prevalence between 8% and 10% depending on whether the AAP CPG or European Society of Hypertension guidelines were used to classify clinic BP.[19] Masked hypertension appears to be more common in patients with chronic kidney disease (CKD), repaired aortic coarctation, and obesity (Table 2).[20–22] Regardless of the pathogenesis, masked hypertension has been shown to be associated with increased left ventricular mass in youth who have these high-risk conditions.[23,24]

Usefulness in Chronic Conditions

Abnormal circadian BP patterns are common in children with specific underlying diagnoses. Nocturnal hypertension is common in children with sickle cell disease,[25] CKD,[26] obstructive sleep apnea,[27] systemic lupus erythematosus,[28] and autosomal dominant polycystic kidney disease[29] and in recipients of solid-organ transplants.[30] Some children with medical diagnoses often thought to have a more benign prognosis have significant abnormalities noted on ABPM: one-third of children with steroid-sensitive nephrotic syndrome have ambulatory hypertension and 72% have nocturnal hypertension[31]; 50% of children born prematurely have abnormal nocturnal BP,[32] as do 82% of children with a solitary kidney.[33] Nocturnal BP abnormalities have been associated with various measures of TOD in diverse patient populations, including type 1 diabetes.[26,28,34]

DETERMINANTS OF ABP

Systemic BP is a result of complex physiological processes that change in response to various factors, including position (supine, sitting, standing), level of physical activity, sleep, and stress. ABPM is designed to evaluate BP across many functional dimensions to provide a more complete view of an individual's BP during normal daily activities.

When establishing normal ABP values in pediatric patients, various characteristics that may affect SBP and DBP should be considered. In children and adolescents, age is an important determinant of both 24-hour SBP and BP variability.[35] Sex is a predictor of higher ABP; male sex is associated with a greater prevalence of high ABP.[35] Overweight and obesity status are also associated with increased ABP.[36]

Activity increases BP; therefore, ABP values are higher than resting clinic BP measurements. One study found that increased physical activity as measured by actigraphy was positively correlated with increases in SBP, diastolic BP (DBP), and heart rate on 24-hour ABPM.[37]

Sleep is another important determinant of BP. Under normal circumstances, BP drops by 10% to 20% during sleep,[10] a phenomenon referred to as dipping. Nondipping (also referred to as blunted dipping) is when the decrease in BP during sleep is <10%, and reversed dipping refers to when the mean sleep BP is higher than the mean wake BP. Nondipping and reversed dipping are associated with increased risk of adverse cardiovascular outcomes in adulthood,[38] but long-term follow-up in youth is lacking.

Other likely determinants of ABP include autonomic tone,[39] vascular stiffness or passive arterial parameters,[40] relative blood volume, and use of pharmacological agents such as stimulants prescribed for attention deficit/hyperactivity disorder.[41]

NORMATIVE DATA FOR ABPM

ABP is different from resting clinic BP, necessitating specific normative data. The most widely used data for this purpose are from Wühl et al,[35] who analyzed ABPM measurements from 949 healthy Central European children 5 to 20 years of age by using the least mean squares method to provide both age-sex–specific and height-sex–specific reference values. Unfortunately, this dataset contains no reference values for children <120 cm in height, and the DBP values have minimal variability across height and age

distributions. In addition, these data were obtained using one specific oscillometric ABPM device. Oscillometric devices estimate BP through device-specific proprietary algorithms that use the measured mean arterial pressure to calculate systolic and diastolic values. Therefore, the calculated SBP and DBP may vary by device, and the use of a device different from that used in the Wühl dataset may affect the patient's classification. A reasonable approach when conducting ABPM with a device other than that used to derive the Wühl data might be to use mean arterial pressure, which should be comparable between different devices.

Newer data from 1445 Chinese children 8 to 17 years of age between 119 and 185 cm in height using a different ABPM device have been published that are higher than the Wühl values.[42] Whether these databases could be combined considering differences in baseline lifestyle and other characteristics merits careful study. In the meantime, the ABP values in the Wühl dataset remain the best available reference in our opinion.

Various new cuffless BP devices are being developed that hold promise for intermittent and continuous ambulatory BP monitoring. A universal protocol to test these devices for accuracy is not yet available, so these devices cannot yet be recommended for pediatric use.

STANDARD APPLICATION OF ABPM

Acceptance of ABPM and recommendations for its routine use in children and adolescents have evolved over time. Although the 2004 Fourth Report stated that ABPM may be useful in a selected number of clinical scenarios, the 2016 European Society of Hypertension pediatric hypertension guideline[43] and the 2017 AAP CPG[5] now endorse much broader use of ABPM in the evaluation and management of hypertension in youth. As will be discussed later in this scientific statement, knowledge gaps regarding several aspects of pediatric ABPM remain; but despite those gaps, ABPM may now be considered a routine procedure in the pediatric hypertension clinic.

We now present our approach to performance of ABPM in children and adolescents in list form, which we hope will prove useful to clinicians.

- Indications for routine performance of ABPM include:
  - To confirm the diagnosis of hypertension in a patient with hypertension on the basis of clinic BP measurements.
    - Distinguish between ambulatory hypertension and WCH.
  - To better assess BP in a patient with clinic BP persistently in the elevated but not hypertensive range.[5]
  - To evaluate for possible masked hypertension when there is a clinical suspicion of hypertension, but clinic BP readings are normal or in the elevated BP range.
  - To assess BP patterns in high-risk patients (Table 2):
    - Assess for abnormal circadian variation in BP, such as abnormal dipping, or isolated nocturnal hypertension in patients with diabetes, CKD, solid-organ transplant, and severe obesity with or without sleep-disordered breathing.
    - Assess the severity and persistence of BP elevation in patients at high risk for hypertensive TOD.
  - To optimize drug therapy for hypertension:
    - Confirm BP control in treated patients[5]
    - Evaluate for pseudo-resistant hypertension[44]
    - Determine if symptoms suggestive of hypotension can be confirmed as such.
- An ABPM device suitable for use in children should be selected:
  - Only oscillometric or auscultatory ABP devices that have been validated according to American National Standards Institute (ANSI)/Association for the Advancement of Medical Instrumentation (AAMI)/International Organization for Standardization (ISO)[45] should be used. The British Hypertension Society[46] standard is acceptable for devices marketed before publication of the ANSI/AAMI/ISO standards.
  - Appropriate cuff sizes as recommended in the 2017 CPG[5] must be available for the device selected.
- Use a standard approach to obtaining ABP studies:
  - Ideally, pediatric ABPM should be performed by personnel trained in the application of the device in children and adolescents, and interpretation of ABPM data in pediatric patients.
  - Place monitors in an office setting to enable checks for accuracy as described later in this scientific statement, and for optimal patient education.
  - Monitors should be applied to the nondominant arm unless contraindicated (eg, presence of a permanent dialysis access).
    - If there is a >5 mm Hg difference in clinic BP between the 2 arms, place the cuff on the arm with the higher BP.
    - In patients with repaired aortic coarctation with normal arch vessel anatomy, place the cuff on the right arm.
  - Devices should be programmed to record BP every 15 to 20 minutes during wake hours and every 20 to 30 minutes during sleep.
  - BP should be measured with the device and compared with resting clinic BP values obtained in the same arm with another validated device using the same technique as the ambulatory device (auscultatory or oscillometric). This can identify potential inaccuracy with ABPM (cuff choice/placement, device requiring repair) and aid interpretation of ABPM measurements.

- Patients should record antihypertensive medication administration, physical exercise periods, unusual activity, sleep, and wake times in a diary.
- An optimal study meets the following criteria:
  - Monitoring period spans 24 hours. Periods as short as 18 to 20 hours can be acceptable if the sleep period is captured and if the criteria stated later in this scientific statement are met.
  - At least 70% of all attempted readings are successful during the monitoring period.[47]
    - Usually this will result in a minimum of 40 to 50 successful readings over the monitoring period.
  - Suboptimal studies can provide clinically useful information, but ideally should be repeated.
    - There should be a minimum of 1 BP reading per hour, including during sleep.
- ABPM recordings should be edited for outlying values:
  - Individual wake and sleep BP and heart rate measurements should be reviewed for values that fall considerably outside the normal ranges for the patient's age
  - Universally, values falling outside the following ranges should be discarded:
    - SBP <60 mm Hg or >220 mm Hg
    - DBP <35 mm Hg or >120 mm Hg
    - Heart rate <40 beats per minute or >200 beats per minute
    - Pulse pressure <40 mm Hg or >120 mm Hg
  - Ideally, these limits should be programmed into the ABPM software to minimize subjective editing of ABPM data.
  - Any resting BP measurements made using the ABPM device immediately after application of the device (eg, test readings) should also be removed.
  - Measurements during vigorous exercise (as indicated by diary data) should be excluded.
- Standard calculations should be reported:
  - Mean ambulatory SBP and DBP during the entire 24-hour, wake, and sleep periods.
  - BP load (percentage of readings above the threshold value) is no longer considered in the classification of ABP phenotype (see rationale in the Blood Pressure Load section).
  - Extent of dipping (percent day-night difference) should be determined ([mean awake BP–mean sleep BP]/mean awake BP] *100) for both SBP and DBP.
  - Patient-recorded wake-sleep times from the diary should be used to denote the wake and sleep periods for analysis.
- ABPM studies should be interpreted using appropriate pediatric normative data:
  - ABPM values should be compared with sex- and height-specific ABP data obtained in large pediatric populations and not with resting BP levels.
- A suggested schema for staging ABPM is included in Table 1.

METHODS FOR PERFORMING ABPM

Nurses and other health care professionals who use ABPM should follow a standardized approach to maintain the functionality of the equipment, minimize measurement errors, and obtain valid, reliable, and reproducible BP data.[10] Care of ABPM equipment includes yearly checks for accuracy; regular inspection of cuffs and tubing for defects, wear/tear, or air leaks; and cleaning the hardware with disinfecting wipes and laundering the reusable BP cuff cloth covers between patients. Before initiating ABPM, review the patient's history for any contraindications such as latex allergy, clotting disorders and significant nocturnal enuresis (which risks getting the device wet).

Serious adverse events related to ABPM have not been reported in children; however, recent data suggest poor tolerability in some adolescents. In a cross-sectional study investigating the effect of hypertension on TOD in 232 adolescents (median age, 15.7 years), 32% were significantly disturbed by the monitoring during wake or sleep hours (17% intolerant awake and 25% during sleep). The study also showed that poor tolerability to ABPM was associated with a higher prevalence of ambulatory hypertension.[48]

The selection of the appropriate size cuff should be in accordance with published guidelines.[5] After application, the ABP should be measured and compared with resting, clinic BP using the same technique used by the ABPM device (auscultatory or oscillometric). If the average of 3 values is more than ±5 mm Hg different, cuff placement should be adjusted, batteries changed, or the device's accuracy confirmed.

Comprehensive, standardized patient and parent education will reduce the failure rate in obtaining accurate ABPM (Appendix 1). Patients and their parents/guardians need instructions on how to stop a reading if there is excessive discomfort, and they should also be told to keep the arm still during readings. To avoid damage to the device, monitors should not be allowed to get wet and should not be worn during contact sports. Removal of the monitor during the 24-hour period 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. Last, children should maintain a diary indicating (1) sleep/wake times; (2) duration of activities that may influence BP measurements, including stressful situations or exercise; (3) timing of antihypertensive medication administration; and (4) any symptoms such as dizziness.

Equipment

Both oscillometric and auscultatory ABP monitors are available for pediatric use, and many have been validated using either the ANSI/AAMI/ISO or the British

Hypertension Society protocols. Devices that have passed this rigorous testing can be identified on several websites:

- American Medical Association[49]
- British and Irish Hypertension Society[50]
- Hypertension Canada[51]
- Stride BP[52]

Unfortunately, monitors that have not undergone validation testing in children are still marketed. There are additional general and child-specific issues related to device selection that are reviewed in the 2014 AHA ABPM statement.[10]

Accounting for Activity

It is important to accurately capture wake, sleep, and periods of increased activity during ABPM.[53] Activity period BPs are shown to be reliably captured on ABPM in general, although some specialists recommend avoidance of vigorous exercise.[54] Recording on a school day should be encouraged, because weekend days may produce lower ABPM results.

Reproducibility

At present, a 24-hour period is recommended for ABP monitoring. According to recent studies, ABPM provides excellent reproducibility at a population level.[55]

INTERPRETATION OF ABPM STUDIES

Previous ABP Classification

The 2014 AHA ABPM statement endorsed a classification schema with 6 categories that relied on the combination of mean ABP and BP load (percentage of ABP readings above the 95th percentile). This schema was not comprehensive, leading to some patients being unclassified. The severe ambulatory hypertension category in the schema also led to confusion, because patients with only mildly elevated mean BP would be labeled as having severe ambulatory hypertension because of loads >50%. A more contemporary concern regarding the 2014 AHA ABPM guidelines is that the 2017 AAP CPG has now aligned classification of clinic BP in adolescents with the 2017 ACC/AHA adult guideline.[5,6] The new adult ABPM guidelines have been revised toward a lower threshold for diagnosis, which in many cases would be below the ambulatory normative data currently endorsed in the 2014 AHA statement.[6]

Blood Pressure Load

Both adult[6] and European Society of Hypertension pediatric guidelines[43] define 4 major ambulatory BP status groups on the basis of clinic and mean ABP (normal, masked hypertension, WCH, and ambulatory hypertension). The 2014 AHA pediatric classification of ABP phenotype[10] is more complex, as mentioned earlier, and includes 2 additional BP stages: ambulatory prehypertension (mean BP, <95th percentile, but BP load ≥25%) and severe ambulatory hypertension (mean BP, ≥95th percentile and BP load >50%). Using 2014 AHA categories may lead some patients to be unclassified if they have elevated BP load but normal mean ambulatory BP and clinic BP that is either normal (<90th percentile) or hypertensive (≥95th percentile). In addition, the role of prehypertension in predicting clinical outcomes or subclinical TOD is unclear.

The utility of isolated increased BP load in predicting hypertensive TOD in children has been assessed recently in children with CKD and in otherwise healthy children. A report from the CKiD (Chronic Kidney Disease in Children Study) showed no clear benefit of using BP load in addition to mean ABP in predicting CKD progression or LVH in children with CKD stages 2 to 4.[56] Likewise, in the SHIP AHOY study (Study of High Blood Pressure in Pediatrics: Adult Hypertension Onset in Youth) of otherwise healthy adolescents, BP load was not independently associated with LVH and did not improve prediction of LVH if added to the mean BP levels in the models.[13] These new data from intermediate outcome-based studies justify a revision to simplify ABPM interpretation, including elimination of BP load from ABPM classification (Table).

Use of Single BP Cut Point Versus BP Percentiles in Adolescents

Although the 2017 AAP CPG[5] adopted the adult definition of clinic hypertension (≥130/80 mm Hg) for both boys and girls ≥13 years of age, the 2014 AHA definition of ambulatory hypertension is based on the sex/height- or sex/age-specific 95th percentiles and BP load for all ages without consideration of adult cut points.[10] In tall and older adolescents, particularly boys, the 95th percentile values are higher than either European Society of Hypertension (mean wake BP, 135/85 mm Hg, mean sleep BP, 120/70 mm Hg, and mean 24-hour BP, 130/80 mm Hg) or ACC/AHA adult cutoffs (mean wake BP, 130/80 mm Hg, mean sleep BP, 110/65 mm Hg, and mean 24-hour BP, 125/75 mm Hg). For example, the 95th percentile SBPs for a 16-year old boy are wake 144 mm Hg, sleep 126 mm Hg, and 24-hour 138 mm Hg. Recent analyses demonstrated that the use of adult absolute ABP values to define ambulatory hypertension was comparable to sex- and height-based 95th percentiles in predicting LVH in adolescents ≥13 years of age. For DBP, the SHIP AHOY analysis found no significant association of any diastolic ABP cutoffs (pediatric or adult) with LVH. The new adult ABP thresholds are lower than the 95th percentile wake and 24-hour SBP for boys who are ≥12 years of age or ≥160 cm tall and lower than the 95th percentile sleep SBP for boys ≥8 years of age or ≥135 cm tall. Similarly, for mean sleep SBP, the 95th percentile is higher than adult cutoffs for girls as young as 7 years of age and as tall as 140 cm. In addition, regardless of age or height (exclusive of very short

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Table 3. Gaps in Knowledge in Pediatric ABP Monitoring

Equipment	Insufficient numbers of ABP devices have been validated in youth.
	There are inaccuracies in measurement of DBP with oscillometric devices.
Normative data are lacking	Across race and ethnicity
	For children who are younger and have lower height
	Although home BP has been found to be more reliable in predicting elevated left ventricular mass index versus office or ABPM in adults,[6] data comparing clinic, ABP, and home BP in children are sparse.[5]
	Data on expected ABP values in subpopulations such as cancer survivors and transplant patients are lacking.
Outcomes	The only randomized clinical trial[4] that proved that the use of ABP led to improved outcomes was conducted in youth with chronic kidney disease.
	Whether nocturnal hypertension or WCH progress to sustained ambulatory hypertension is unknown.
	Limited data are available linking ABP values across race and ethnicity to intermediate cardiovascular outcomes such as left ventricular mass, carotid intima-media thickness, and arterial stiffness.
	Randomized clinical trials comparing the efficacy of antihypertensive medications to reduce ABP have not been performed.
	Improvement in the ability to predict hard CVD outcomes in adults by using ABPM, rather than clinic BP, performed in youth cannot be established.
ABPM interpretation	The number of ABPM readings obtained in a 24-h period that are needed to predict outcomes (eg, left ventricular hypertrophy) is unknown.
	The long-term consequences of WCH, masked hypertension, isolated nocturnal hypertension, and nondipping are unknown.
	The clinical relevance of morning surge in ABP in pediatrics has not been evaluated.
Cost-effectiveness and utility	Limited data on the cost-effectiveness of use of ABPM to reduce costs (through reducing the number of clinic visits) are available.
	Practical solutions for cost reduction through volume discount purchasing and sharing of devices are needed to increase access to devices.
	The influence of patient/family–specific factors (including social determinants of health) on the accuracy and precision of ABPM in children and adolescents has not been explored.

ABP indicates ambulatory blood pressure; ABPM, ambulatory blood pressure monitoring; BP, blood pressure; CVD, cardiovascular disease; DBP, diastolic blood pressure; and WCH, white coat hypertension.

or young children), most of the 95th percentiles for DBP for both boys and girls are above ACC/AHA adult thresholds. Given the similarities in adult and adolescent longitudinal outcome studies and the progressive and cumulative nature of BP-related TOD, the lower of either the 95th percentile or the adult cutoff should be used to categorize ABP in children <13 years of age (Table 1).

Diastolic Hypertension

The 2014 AHA statement[10] recognized that some patients, likely those with secondary hypertension, could have isolated diastolic hypertension on ABPM and endorsed using DBP and SBP, as well, in the interpretation of ABPM studies, with abnormalities in either sufficing for diagnosis. Since then, evidence continues to emerge that ambulatory diastolic hypertension can discriminate between primary and secondary hypertension. In a study of 168 hypertensive children conducted in Poland, patients with secondary forms of hypertension had significantly higher mean DBP and DBP loads for all time periods than children with primary hypertension, although the children with secondary hypertension were younger.[57]

At the same time, there is uncertainty regarding DBP measurement by ABPM, primarily because most ABPM devices used in pediatrics measure BP by the oscillometric technique, which appears to perform less well for diastolic than SBP in validation studies.[58] In addition, the widely used normative data for pediatric ABPM[35] show a striking lack of variability for DBP according to age and height, which is likely related to the use of the oscillometric technique. However, as indicated in the 2014 AHA statement,[10] the wake 95th percentile DBP values found in the Wühl pediatric ABPM database are high (82–84 mm Hg, similar for boys and girls and similar regardless of height), so sustained DBP above this value would likely be considered hypertensive by most clinicians. Thus, we feel that DBP should continue to be used as part of the interpretation of ABPM studies.

Nocturnal Hypertension

The 2014 AHA statement[10] also recommended that patients can be considered to have ambulatory hypertension solely on the basis of nocturnal BP elevation. Several lines of evidence support this, including the high prevalence of isolated nocturnal hypertension in solid-organ transplant recipients,[29] patients with obstructive sleep apnea,[27] and patients with CKD.[59] Children and adolescents with obesity have also been shown to have nocturnal hypertension and blunted nocturnal BP dipping.[60] Nocturnal hypertension has been associated with abnormal cardiovascular parameters such as LVH and increased cIMT in patients with CKD[26] and diabetes,[61] and abnormal nocturnal BP dipping has been associated with impaired endothelial function in hematopoietic cell transplant recipients.[62] Therefore, we have concluded that abnormalities of sleep BP should be given the same weight as abnormalities of wake BP.

CONCLUSIONS AND FUTURE DIRECTIONS

After careful review of recent data, we have updated our guidance for the use of ABPM in youth in several important ways. First, consistent with the 2017 AAP CPG, we suggest the use of ABPM to confirm the diagnosis of hypertension before starting antihypertensive medication.[5] Second, additional resources that evaluate validation of automatic BP

devices are supplied. Finally, a new schema for classifying ABP is provided (Table 1). This new system eliminates the use of BP load, which has recently been shown to be of no additional value over mean BP in predicting LVH and uses a single static cut point to define ambulatory hypertension. Not only is the new cut point consistent with adult guidelines, recent data show also that ABP phenotypes defined with this new system are superior in predicting BP-related TOD. However, there are still many knowledge gaps to address in future research (Table 3). Even recognizing that these gaps exist, and that ABPM may not be universally available, ABPM is clearly an important technique that adds precision to the evaluation and management of the young patient with elevated BP. It is hoped that this scientific statement will assist pediatric practitioners in applying these techniques in their own clinic populations.

ARTICLE INFORMATION

The American Heart Association makes every effort to avoid any actual or potential conflicts of interest that may arise as a result of an outside relationship or a personal, professional, or business interest of a member of the writing panel. Specifically, all members of the writing group are required to complete and submit a Disclosure Questionnaire showing all such relationships that might be perceived as real or potential conflicts of interest.

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Disclosures

Writing Group Disclosures

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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 (a) the person receives $10 000 or more during any 12-month period, or 5% or more of the person's gross income; or (b) 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.

*Modest.

†Significant.

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*Modest.

APPENDIX 1

DIRECTIONS FOR AMBULATORY BLOOD PRESSURE MONITOR

Wearing the Monitor

- The blood pressure monitor will take a blood pressure reading every 20 minutes while the wearer is awake and every 30 minutes while they sleep. There may be a soft beep indicating the monitor is getting ready to inflate and take a blood pressure. This sound will be off during the night.
- When the cuff inflates, let your arm hang limp and relaxed at your side until the cuff deflates. Excess movement will make it difficult for the monitor to take a reading. If the monitor cannot take the measurement, it will stop the reading and will try again in 2 minutes.
- If the monitor seems to be going off too frequently, the cause may be too much movement. Be sure to keep the arm still during measurement.
- The blood pressure reading will not be displayed after the 5th reading or 30 minutes. You will only see dashes, or you may see nothing on the display.
- Place the monitor under a pillow during sleep to protect it and minimize vibrations.
- The blood pressure cuff and monitor may be removed between readings for changes of clothes and bathing. Please do not turn off the monitor during that time.
- After the 24-hour time period, turn off and remove the cuff and monitor. When turning off the monitor, hold it tightly and hold it over a soft surface such as bed or couch. Press the on/off switch as instructed.

Troubleshooting Problems

- If the cuff is hurting your arm, undo the Velcro and reapply the cuff. Make sure that it does not slide when gently tugged on with both thumbs. During the wearing, your arm may eventually get a little sore, but it should not hurt.
- If your arm is being held still during a measurement, but the measurements are occurring more often than expected, please check for the following:
  - The cuff is not loose or sliding down your arm. If it is loose, reapply the cuff, taking care to tighten the cuff so that, when you tug on it gently with both thumbs, it does not slide down, but is still comfortable.
  - There are no kinks, blockages, or obstructions in the tubing from the cuff to the monitor.
- If the cuff inflates at an inappropriate time, for example, you are waving your arm, press the start/stop button and the cuff will deflate and not take that reading.

Avoiding Damage to the Monitor

- Do not allow any liquids or fluid (water, drinks, urine) to come into contact with the monitor. Do not swim, bathe, or wash dishes while wearing it. If you have trouble wetting the bed at night, please let your health care team know.
- Avoid all contact sports while wearing the monitor.

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