AHA Scientific Statement

Measurement of Blood Pressure in Humans

A Scientific Statement From the American Heart Association

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***Abstract*—**The accurate measurement of blood pressure (BP) is essential for the diagnosis and management of hypertension. This article provides an updated American Heart Association scientific statement on BP measurement in humans. In the office setting, many oscillometric devices have been validated that allow accurate BP measurement while reducing human errors associated with the auscultatory approach. Fully automated oscillometric devices capable of taking multiple readings even without an observer being present may provide a more accurate measurement of BP than auscultation. Studies have shown substantial differences in BP when measured outside versus in the office setting. Ambulatory BP monitoring is considered the reference standard for out-of-office BP assessment, with home BP monitoring being an alternative when ambulatory BP monitoring is not available or tolerated. Compared with their counterparts with sustained normotension (ie, nonhypertensive BP levels in and outside the office setting), it is unclear whether adults with white-coat hypertension (ie, hypertensive BP levels in the office but not outside the office) have increased cardiovascular disease risk, whereas those with masked hypertension (ie, hypertensive BP levels outside the office but not in the office) are at substantially increased risk. In addition, high nighttime BP on ambulatory BP monitoring is associated with increased cardiovascular disease risk. Both oscillometric and auscultatory methods are considered acceptable for measuring BP in children and adolescents. Regardless of the method used to measure BP, initial and ongoing training of technicians and healthcare providers and the use of validated and calibrated devices are critical for obtaining accurate BP measurements. **(*Hypertension*. 2019;73:e•••–e•••. DOI: 10.1161/HYP.0000000000000087.)**

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Hypertension

According to the 2017 American College of Cardiology (ACC)/American Heart Association (AHA) guideline for the prevention, detection, evaluation, and management of high blood pressure (BP) in adults, 46% of US adults have hypertension.[1]

The diagnosis and management of hypertension depend on the accurate measurement of BP. The direct measurement of BP requires an intra-arterial assessment. This is not practical in clinical practice, where BP is assessed noninvasively.

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For conciseness, we use the term *BP measurement* for estimates obtained through noninvasive means. Determination of BP for diagnosing hypertension has relied mostly on measurements taken on the arm over the brachial artery during healthcare visits, herein referred to as *office BP*. Before the 21st century, office BP was measured by an observer listening to sounds with a stethoscope while watching a sphygmomanometer (ie, auscultation). However, semiautomated and automated devices that use the oscillometry method, which detects the amplitude of the BP oscillations on the arterial wall, have become widely used over the past 2 decades. In addition, substantial data have accumulated demonstrating that BP is different for many people when measured in the office and outside of the office.[2–4]

The last scientific statement from the AHA on BP measurement in humans was published in 2005.[5] There have been a number of studies that inform the approaches to BP measurement since the 2005 AHA BP measurement scientific statement was published. The writing committee was tasked with updating the AHA scientific statement and providing contemporary information on the measurement of BP in humans.

BP Components

Systolic and Diastolic BP

Systolic BP (SBP) and diastolic BP (DBP) are the most commonly reported BP measures in clinical practice and research studies because they are well-established cardiovascular disease (CVD) risk factors and can be directly estimated. When considered separately, higher SBP and higher DBP are associated with increased CVD risk.[6,7] SBP is associated with CVD events independently of DBP.[8–10] In contrast, in some studies, DBP has not been associated with CVD events after adjustment for SBP, especially in older populations.[11,12]

Pulse Pressure, Mid-BP, and Mean Arterial Pressure

Several additional BP measures can be calculated from SBP and DBP. Pulse pressure (SBP−DBP) is a measure of pulsatile hemodynamic stress and a marker of arterial stiffness. Mid-BP (the average of SBP and DBP) and mean arterial pressure (often approximated for individuals with normal heart rate as 1/3 SBP+2/3 DBP or DBP+1/3 pulse pressure) provide estimates of the overall arterial BP during a complete cardiac cycle. Although higher levels of pulse pressure and mid-BP have been associated with increased risk for CVD events independently of other BP components, SBP and DBP remain the most commonly reported BP measures and continue to be used in hypertension management guidelines, including the 2017 Hypertension Clinical Practice Guidelines, the 2013 European Society of Hypertension (ESH)/European Society of Cardiology guideline, and the 2018 ESH/European Society of Cardiology guideline.[1,13,13a]

BP Measurement in the Office

Overview

In the office setting, BP is measured noninvasively in 2 ways. The traditional method involves auscultation of the brachial artery with a stethoscope to detect the appearance and muffling or disappearance of the Korotkoff sounds, which represent SBP and DBP, respectively.[14] Over the past 20 to 30 years, the oscillometric technique, wherein software within a device evaluates the oscillometric waveforms, commonly during BP cuff deflation, and uses algorithms to estimate BP, has been developed and refined.[15] Regardless of who is measuring BP or the method used (eg, auscultatory or oscillometric), the accuracy of the BP readings relies on standardized techniques and appropriate observer training. Sources of BP measurement error include patient-related (eg, recent food consumption, movement), device-related (eg, using a noncalibrated or nonvalidated device) and procedure-related (eg, talking during the procedure or miscuffing) factors. The use of an inaccurate measurement technique is common, and a systematic review found a large bias associated with 27 of 29 potential sources of BP measurement error.[16] Table 1 lists key components of observer training for BP measurement.

Key Points for Accurately Measuring Office BP

An initial step in measuring BP is determining the appropriate cuff size (Tables 2 and 3). BP measurement is most commonly made in either the seated or the supine position. Seated measurements are preferred given the large amount of data correlating BP obtained in this position with outcomes. Regardless of whether BP is measured in the seated or supine position, the BP cuff should be at the level of the patient's right atrium (Table 4). Other key points related to proper BP measurement from the 2017 Hypertension Clinical Practice Guidelines are provided in Table 5. Using a cuff that is too small will result in an artificially elevated BP reading, and using a cuff that is too large will result in a reading that is artificially low.[16] Other effects on SBP and DBP from not following measurement recommendations are provided in a recent systematic review.[16]

Cuff Placement and Stethoscope

The observer must first palpate the brachial artery in the antecubital fossa and place the center of the bladder length of the cuff (commonly marked on the cuff by the manufacturer) so that it is over the arterial pulsation of the patient's bare upper arm. The lower end of the cuff should be 2 to 3 cm above the antecubital fossa. When an auscultatory measurement is being taken, this allows room for placement of the stethoscope. However, if the bladder is not long enough to sufficiently encircle the arm (75%–100% for auscultatory measurements), a larger cuff should be used, recognizing that if the cuff touches the stethoscope, artifactual noise will be generated.[24] The cuff should be pulled taut, with comparable tightness at the top and bottom edges of the cuff, around the bare upper arm. To assess the appropriate tightness, 1 finger should fit easily at the top and bottom of the cuff; 2 fingers should fit but will be very snug. When taking an auscultatory measurement, the cuff should initially be inflated to at least 30 mm Hg above the point at which the radial pulse disappears. Cuff deflation should occur at a rate of 2 mm Hg per second or per heartbeat when the heart rate is very slow to obtain an accurate estimate of BP.

The Auscultatory Technique

The auscultatory or Korotkoff method of measuring BP has been the traditional approach for measuring SBP

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Table 1. Key Components for Training in BP Measurement

Assess physical and cognitive competencies to perform auscultatory BP measurement
Vision: The observer must be able to see the dial of the manometer at eye level without straining and read the sphygmomanometer no further than 3 ft away.
Hearing: The observer must be able to hear the Korotkoff sounds.
Eye/hand/ear coordination: The observer must be able to conduct the cuff deflation, listen to Korotkoff sounds, and read the sphygmomanometer simultaneously.
The evaluation of observers should include an assessment of their knowledge of the following:
The different types of observer bias, especially if measurements are made manually
General techniques and the interpretation of the measurements
Understanding of BP variability by time of day, exercise, and timing of antihypertensive medication consumption
Observers should be aware of the need to do the following:
Use only validated devices that are well maintained (including regular recalibration)
Choose a quiet location with adequate room temperature (≈72°F)
Correctly position the person whose BP is being measured
Ensure that the person does not talk or move during the rest and measurement periods
Ensure that the person does not have a full bladder when BP is measured
The skills of the technician or provider should be demonstrated by assessing the following:
Positioning the patient
Selecting the appropriate size cuff
Obtaining a valid and reliable measurement
Recording the measurement accurately
Reporting of abnormal levels
Observers should also know how to interpret and how and when to communicate BP readings to healthcare providers and patients.
Questionnaires or interviews can be used to assess knowledge of the BP measurement methodology.
Retraining of healthcare professionals every 6 mo to 1 y should be considered.

BP indicates blood pressure.

Training information is available in a web-based video from the British and Irish Hypertension Society.[17]

Table 2. Key Points in Selecting Cuff Sizes for BP Measurement

Arm circumference should be measured at the midpoint of the acromion and olecranon.
BP cuff bladder length should be 75%–100% of the patient's measured arm circumference.
BP cuff bladder width should be at 37%–50% of the patient's arm circumference (a length-to-width ratio of 2:1)
BP cuff should be placed on bare skin.
Shirtsleeves should not be rolled up because this may create a tourniquet effect.
The most frequent error in measuring office BP is "miscuffing," with undercuffing large arms accounting for 84% of the miscuffings.[18,19]
There is variation in the BP cuff bladder length for adult and large adult cuffs (ie, the bladder size for large cuff may differ between manufacturers).
Individual cuffs should be labeled with the ranges of arm circumferences; lines should be added that show whether the cuff size is appropriate when it is wrapped around the arm.
Information on cuff selection for patients with morbid obesity is provided in the Obese Patients section.

BP indicates blood pressure.

and DBP.[25–27] However, for reasons described in Types of Sphygmomanometers, the auscultatory method of BP measurement is being replaced by the use of oscillometric devices in both clinical practice and research settings. To conduct auscultatory measurements, a BP cuff is wrapped around the patient's arm and inflated, causing the brachial artery to be occluded and flow through the artery to stop. As the cuff is gradually deflated, blood flow is re-established and accompanied by sounds that can be heard with a stethoscope held over the brachial artery at the antecubital space. Inflation that is too rapid can affect the BP reading, and a deflation rate that is too rapid (ie, faster than 2–3 mm Hg/s) can impede the ability to reliably identify the BP levels of the Korotkoff sounds. In patients with slow heart rates (eg, <60 bpm), a rate of deflation that is too rapid will lead to errors in BP measurement. The sequence of sounds is as follows: phase 1, sudden appearance of sharp tapping sounds, considered to be SBP; phase 2, swishing sounds; phase 3, regular, louder sounds; phase 4, abrupt muffling of sounds; and phase 5, loss of all sounds, considered to be DBP.[25,27,28]

Types of Sphygmomanometers

Mercury Sphygmomanometers

The auscultatory method using a mercury sphygmomanometer has been the reference standard for office BP measurement for several decades. The mercury sphygmomanometer has a simple design and is not subject to substantial variation across models made by different manufacturers. Although used in some research studies, the mercury sphygmomanometer has been replaced in many clinic settings because of environmental concerns about mercury toxicity.[29] One type of mercury sphygmomanometer, the random-zero sphygmomanometer, was designed to eliminate observer bias in research studies. However, the random-zero sphygmomanometer has

Table 3. Illustrative Cuff Sizes Corresponding to a Patient's Arm Size

Cuff Size	Arm Circumference, cm	Bladder Dimension (width×length), cm*
Small adult	22–26	12×22
Adult	27–34	16×30
Large adult	35–44	16×36
Extra-large adult	45–52	16×42

*Bladder and cuff size may differ by manufacturer.

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Table 4. Body Position and BP Measurement

SBP has been reported to be 3–10 mm Hg higher in the supine than the seated position.[20]
DBP is ≈1–5 mm Hg higher when measured supine vs seated.[20]
In the supine position, if the arm is resting on the bed, it will be below heart level.
When BP measurements are taken in the supine position, the cuffed arm should be supported with a pillow.
In the seated position, the right atrium level is the midpoint of the sternum or the fourth intercostal space.
If a patient's back is not supported (eg, the patient is seated on an examination table), SBP and DBP may be increased by 5–15 and 6 mm Hg, respectively.[21]
Having legs that are crossed during BP measurement may raise SBP by 5–8 mm Hg and DBP by 3–5 mm Hg.[22]
If the upper arm is below the level of the right atrium (eg, when the arm is hanging down while in the seated position), the readings will be too high.
The cuffed arm should be held up by the observer or resting on a table at heart level. If the arm is held up by the patient, BP will be raised.

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

been found to underestimate BP compared with measurements with a traditional mercury sphygmomanometer.[30–33]

Aneroid Sphygmomanometers

Aneroid sphygmomanometers have become common in the clinic setting for the auscultatory method since the removal of mercury devices. These devices have an aneroid gauge that consists of metal bellows with a watch-like movement connected to a compression cuff. Variations of pressure within the system cause the bellows to expand and contract. Movement of the bellows rotates a gear that turns a pointer pivoted on bearings, across a calibrated dial. Aneroid sphygmomanometers are susceptible to error and loss of calibration, especially when handled harshly.[34] Wall-mounted aneroid devices are less susceptible to trauma and therefore may require less frequent calibration than mobile devices. Calibration, every 6 months for wall-mounted and every 2 to 4 weeks for handheld devices, is needed to ensure the accuracy of aneroid devices.[35]

Hybrid Sphygmomanometers

A hybrid sphygmomanometer uses the auscultatory approach but replaces the mercury column with an electronic pressure gauge. With a hybrid sphygmomanometer, a liquid crystal display column or light-emitting diode screen moves smoothly like a mercury column or aneroid-like display. As with all auscultatory methods, an observer must still listen for Korotkoff sounds (phases 1 and 5) and record BP values. A study evaluating hybrid monitors found them to be a reliable alternative to mercury and aneroid sphygmomanometer devices.[36,37] The frequency with which hybrid sphygmomanometers should be calibrated is unknown.

The Oscillometric Technique

Oscillometric devices are commonly used to measure BP in clinic, ambulatory, home, and hospital settings, with readings based on the amplitude of the oscillations recorded in the lateral walls of the upper arm. Most oscillometric devices estimate BP when the cuff is being deflated, but some devices obtain estimates on inflation. Mean arterial BP is estimated to be the cuff pressure when the oscillation amplitude is maximal, and then the SBP and DBP are computed.[5,34,38] SBP and DBP estimation from mean arterial BP is commonly performed via fixed ratios of the maximal oscillation amplitude. Each oscillometric device uses a proprietary algorithm that is known only to the manufacturer. These algorithms can be modified by the device manufacturer, and there are no requirements for such changes to be reported. Therefore, different devices, even from the same manufacturer, are not interchangeable, and only those that have been independently validated with an established protocol should be used (see the Protocols for the Validation of BP Monitors section).[39]

Types of Oscillometric Devices

Several electronic oscillometric sphygmomanometers are currently being used for office BP measurement. Devices originally developed for self-measurement in the home have been adapted for office use.[40] However, because these devices were not specifically designed for the office setting, they may lack durability and reliability. Professional oscillometric sphygmomanometers used by healthcare providers are relatively expensive and have been used mostly in hospital settings to measure 1 BP reading at a time.[41] During the past 15 years, fully automated oscillometric sphygmomanometers capable of taking multiple readings with a single activation have become available, making automated office BP (AOBP) measurement possible. In contrast, semiautomated devices take only 1 reading with each activation.

Automated Office BP

AOBP monitors refers to those with the capability to record multiple BP readings after a rest period with a single activation. Current AOBP devices provide an average of these readings, and it is not necessary to discard the first reading. AOBP can be performed with or without staff being present, which is referred to as *attended* and *unattended AOBP*, respectively. Valid unattended AOBP readings can be obtained with the patient resting quietly in an office examination room or waiting room,[42] with readings taken in different locations reported to be comparable.[43] Several AOBP oscillometric devices have been validated and used in research studies.[44–46]

AOBP as an Alternative to Auscultatory BP in Clinical Practice

Several studies have reported that BP measured with AOBP versus the auscultatory method is closer to awake out-of-office BP levels measured with ambulatory BP monitoring (ABPM). In the CAMBO trial (Conventional Versus Automated Measurement of BP in the Office), AOBP was compared with auscultatory office BP on hypertension management in routine, community-based clinical practice.[47] In CAMBO, 88 primary care physicians in 67 practices in 5 cities in eastern Canada were randomized to either use of AOBP or continued use of an auscultatory office BP.[47] The primary outcome, the difference between SBP at the first office visit after enrollment and mean awake SBP on ABPM, was smaller in the AOBP group (2.3 mm Hg) compared with the control group of practices

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Table 5. Overview of Proper Seated BP Measurement in the Office

Key Steps for Proper BP Measurements	Specific Instructions
Step 1: Properly prepare the patient	1. Have the patient relax, sitting in a chair with feet flat on floor and back supported. The patient should be seated for 3–5 min without talking or moving around before recording the first BP reading. A shorter wait period is used for some AOBP devices.
	2. The patient should avoid caffeine, exercise, and smoking for at least 30 min before measurement.
	3. Ensure that the patient has emptied his/her bladder.
	4. Neither the patient nor the observer should talk during the rest period or during the measurement.
	5. Remove clothing covering the location of cuff placement.
	6. Measurements made while the patient is sitting on an examining table do not fulfill these criteria.
Step 2: Use proper technique for BP measurements	1. Use an upper-arm cuff BP measurement device that has been validated, and ensure that the device is calibrated periodically.
	2. Support the patient's arm (eg, resting on a desk). The patient should not be holding his/her arm because isometric exercise will affect the BP levels.
	3. Position the middle of the cuff on the patient's upper arm at the level of the right atrium (midpoint of the sternum).
	4. Use the correct cuff size such that the bladder encircles 75%–100% of the arm.
	5. Use either the stethoscope diaphragm or bell for auscultatory readings.
Step 3: Take the proper measurements needed for diagnosis and treatment of elevated BP/hypertension	1. At the first visit, record BP in both arms.* Use the arm that gives the higher reading for subsequent readings.
	2. Separate repeated measurements by 1–2 min.
	3. For auscultatory determinations, use a palpated estimate of radial pulse obliteration pressure to estimate SBP. Inflate the cuff 20–30 mm Hg above this level for an auscultatory determination of the BP level.
	4. For auscultatory readings, deflate the cuff pressure 2 mm Hg/s, and listen for Korotkoff sounds.
Step 4: Properly document accurate BP readings	1. Record SBP and DBP. If using the auscultatory technique, record SBP and DBP as the onset of the first of at least 2 consecutive beats and the last audible sound, respectively.
	2. Record SBP and DBP to the nearest even number.
	3. Note the time that the most recent BP medication was taken before measurements.
Step 5: Average the readings	Use an average of ≥2 readings obtained on ≥2 occasions to estimate the individual's BP.
Step 6: Provide BP readings to patient	Provide patients their SBP/DBP readings both verbally and in writing. Someone should help the patient interpret the results.

AOBP indicates automated office blood pressure; BP, blood pressure; DBP, diastolic blood pressure; and SBP, systolic blood pressure.

*When a BP measurement is obtained in 1 arm followed by the other arm and the BP is substantially lower in the second arm, it is possible that the difference could be caused by acclimation. In this circumstance, BP should be remeasured in the first arm.

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randomized to measuring their patients' BP with auscultatory devices (6.5 mm Hg). Moreover, the correlation between awake BP on ABPM and AOBP was statistically significantly stronger compared with the correlation between awake BP on ABPM and auscultatory BP. Less frequent digit preference and a stronger correlation with awake BP on ABPM have been reported for AOBP compared with auscultatory BP in clinical practice.[48,49] On the basis of comparative BP data from 14 studies (13 articles) involving 3410 participants in different settings, an AOBP of 135/85 mm Hg has been estimated to correspond to an awake BP on ABPM of 135/85 mm Hg (Table 6).[42,43,46,49–57] Although fewer data are available, SBP/DBP of 130/80 mm Hg on AOBP is reported to be equivalent to values of awake SBP/DBP of 130/80 mm Hg on ABPM.[48,50,51] AOBP has also demonstrated a stronger association with subclinical CVD, including intima-media thickness of the carotid artery[58] and left ventricular mass index, compared with BP measured with the auscultatory technique by a research technician.[54] Among adults not taking antihypertensive medication, a graded increased risk for fatal and nonfatal CVD events has been reported with AOBP from an SBP of 110 to 119 to ≥160 mm Hg and from a DBP of 60 to 69 to ≥90 mm Hg.[59,60] In adults taking antihypertensive medication, on-treatment SBP measured with an AOBP device without an observer present (unattended AOBP) in the range of

Table 6. Studies Comparing AOBP With Awake Ambulatory BP

Study	Participants, n	Population	Type of BP Measurement, mm Hg	
			Automated Office SBP/DBP	Awake Ambulatory SBP/DBP
Myers et al[48]	309	ABPM unit	132/75	134/77
Beckett and Godwin[49]	481	Family practice	140/80	142/80
Myers et al[43]	62	Hypertension clinic	140/77	141/77
Myers et al[50]	200	ABPM unit	133/72	135/76
	200	ABPM unit	132/76	134/77
Myers[51]	254	ABPM unit	133/80	135/81
Godwin et al[52]	654	Family practice	139/80	141/80
Myers et al[53]	139	ABPM unit	141/82	142/81
Myers et al[47]	303	Family practice	135/77	133/74
Andreadis et al[54]	90	Hypertension clinic	140/88	136/87
Myers et al[53]	100	ABPM unit	137/79	139/80
Padwal et al[55]	100	Research unit	136/79	136/80
Armstrong et al[42]	422	ABPM unit	141/83	139/81
Ringrose et al[56]	96	ABPM unit	131/82	143/84
Mean			136.4/79.3	137.9/79.6

ABPM indicates ambulatory blood pressure monitoring; AOBP, automated office blood pressure; BP, blood pressure; DBP, diastolic blood pressure; and SBP, systolic blood pressure.

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110 to 119 mm Hg has been associated with the lowest CVD event rate.[61]

AOBP in Population Studies and Clinical Practice

As a result of the limitations of routine auscultatory BP measurement in clinical practice, including reliance on the observer's skills, white-coat effect, digit preference, and calibration issues, AOBP recently became the recommended method for diagnosing hypertension and managing BP among patients with hypertension in the Canadian guidelines.[62] Its adoption into primary care has proved feasible in Canada with minimal increases in staff time and effort.[63] The total time required for conducting AOBP is 4 to 6 minutes, including a 1-minute or no rest period before the first measurement, versus a 7- to 8-minute duration, including a 5-minute rest period before the first measurement, for auscultatory and semiautomated devices. A major advantage is the reduced need for staff presence during BP measurement. The Canadian guidelines include a recommendation for AOBP to be conducted with staff absent (unattended AOBP) from the room during BP measurement.[62] Earlier reports have suggested that BP readings taken with staff present may result in higher readings than those obtained with staff absent during measurement.[64] More recent data suggest that the effect of staff presence during BP measurement may be overestimated.[65–67] However, studies not reporting a difference in BP values when measured with attended versus unattended AOBP followed a rigorous protocol that, among other items, instructed the medical staff not to talk or interact with the patient while the BP procedure was being conducted. Considering the current shift away from manual BP measurement and the recommendation to obtain multiple BP readings at a single visit, AOBP may be preferred for use in clinical practice. Because having an observer present when BP readings are obtained may lead to inaccurate values (eg, if the patient or observer is talking), it is preferred to have the patient in a room alone for BP measurements (ie, unattended AOBP).

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Number of Measurements During a Visit

For many people, the first BP measurement taken during an office visit is higher than subsequent measurements. A study of US adults estimated that 35% of people with SBP/DBP on their first BP measurement of 140 to 159/90 to 99 mm Hg had SBP/DBP <140/90 mm Hg when the average of 3 measurements was used.[68] In addition, 24% of participants with SBP/DBP of 120 to 139/80 to 89 mm Hg based on their first clinic measurement had SBP/DBP <120/80 mm Hg based on the average of their second and third measurements. Only 3% of people with SBP/DBP <140/90 mm Hg based on a single measurement had SBP/DBP ≥140/90 mm Hg based on the average of 3 measurements. In a study of men taking antihypertensive medication, at least 5 BP measurements were needed to be 80% certain whether SBP was <140 mm Hg or not.[69] The 2017 Hypertension Clinical Practice Guidelines recommend measuring BP ≥2 times at a clinic visit.[1]

Interarm Differences

Guidelines recommend that BP should be measured in each arm at an initial visit and that the arm with the higher BP should be used at subsequent visits.[13a] Persistent differences in measured BP between the arms that would be considered clinically significant (ie, SBP or DBP difference ≥10 mm Hg) are quite common. A large difference might be caused by coarctation of the aorta or upper-extremity arterial obstruction.

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A systematic review of simultaneously measured SBP in both arms found a pooled prevalence of an interarm difference in SBP ≥10 mm Hg of 11.2% (95% CI, 9.1–13.6) among those with hypertension and 3.6% (95% CI, 2.3–5.0) in the general population.[70] Although poorly reproducible, except in the presence of arterial obstruction, larger interarm BP differences have been associated with increased risk for CVD events.[71–73] When BP is measured sequentially in a person's arms (ie, a measurement in 1 arm followed by the other arm) and the BP is substantially lower in the second arm, it is possible that the difference could be the result of acclimation. In this circumstance, BP should be remeasured in the first arm. When a persistent difference in BP between arms is present, the diagnosis of hypertension should be based on BP measured in the arm with the higher level.

Frequency of Visits

To increase hypertension awareness, it is reasonable to measure BP at every clinic visit. However, for screening for hypertension in adults, measuring BP annually as opposed to at every clinical visit improves specificity for diagnosing hypertension without a reduction in sensitivity.[74] Adults 18 to 39 years of age with office-measured SBP/DBP <120/80 mm Hg who do not have other hypertension risk factors can space the screenings out to every 3 to 5 years. The US Preventive Services Task Force recommends annual BP screening for adults at increased risk for hypertension.[2] This would include patients with elevated BP who are overweight or obese or black. For a patient with SBP/DBP ≥160/100 mm Hg at an office visit, the diagnosis of hypertension can be made and treatment can be initiated without follow-up readings.[1] For most other adult patients, the finding of office BP consistent with hypertension at an initial visit should be confirmed at a follow-up visit within 1 month, with ≥2 BP measurements at each visit. In addition, the US Preventive Services Task Force and the 2017 Hypertension Clinical Practice Guidelines recommend confirmation of office BPs by ABPM or home BP monitoring (HBPM) for the initial diagnosis of hypertension and BP control (see the Twenty-Four–Hour ABPM and the Home BP Monitoring sections). In addition, it is reasonable to reassess BP after 3 to 6 months of nonpharmacological therapy among patients with elevated BP (SBP 120–129 mm Hg with DBP <80 mm Hg). For patients with established hypertension taking antihypertensive medication, the 2017 Hypertension Clinical Practice Guidelines recommend having patients return at approximately monthly intervals after initiating/titrating antihypertensive medication until their goal BP is reached.[1] This aligns with the intervals for the first 3 months after randomization in the Systolic Blood Pressure Intervention Trial.[75] Once BP is at goal, visits can be conducted at 3- to 6-month intervals.[1]

Reproducibility of Mean Office BP

Because BP varies beat-to-beat, perfect reproducibility of mean office BP is not possible. Routine office BP measurements obtained in clinical practice with the auscultatory method demonstrate substantial variability. Therefore, low reproducibility is present over visits conducted days to weeks (short term) and months to years (long term) apart.[76–78]

Table 7. Categories of BP Among Adults According to the 2017 ACC/AHA Guideline for the Prevention, Detection, Evaluation, and Management of High BP in Adults

BP Category	SBP, mm Hg		DBP, mm Hg
Normal	<120	and	<80
Elevated	120–129	and	<80
Hypertension			
Stage 1	130–139	or	80–89
Stage 2	≥140	or	≥90

BP is based on an average of ≥2 careful readings obtained on ≥2 occasions, as detailed in the Home BP Monitoring section. Adults with SBP and DBP in different categories should be designated to the higher category. ACC/AHA indicates American College of Cardiology/American Heart Association; BP, blood pressure; DBP, diastolic blood pressure; and SBP, systolic blood pressure.

Adapted from Whelton et al.[1] Copyright © 2017, by the American College of Cardiology Foundation and the American Heart Association, Inc.

Evidence suggests that high-quality, standardized office BP measurements, as typically obtained in research studies, with the auscultatory or the oscillometric method have better reproducibility than routine office BP obtained in real-world practice settings.[79–81] Although few data are available, AOBP has demonstrated high short-term reproducibility.[43]

Normative Values for Office BP

The 2017 Hypertension Clinical Practice Guidelines provided a new categorization of BP levels. This guideline defined BP categories of normal, elevated, or stage 1 or 2 hypertension (Table 7). SBP/DBP thresholds of 130/80 mm Hg now define the diagnosis of hypertension. Estimates from the 2011 to 2014 National Health and Nutrition Examination Survey indicate that 42.3% and 12.1% of US adults have normal and elevated BP, respectively, and 45.6% have hypertension.[82]

Twenty-Four–Hour ABPM

Overview

ABPM is a noninvasive, fully automated technique in which BP is recorded over an extended period of time, typically 24 hours. ABPM has been available for >40 years.[4] Over the past 2 decades, substantial data have demonstrated that BP measured by ABPM has a stronger association with hypertension-related target-organ damage and clinical cardiovascular outcomes compared with office-based BP measurements.[83,84] Although evidence has accumulated on the value of ABPM and it is recommended to confirm the diagnosis of hypertension in the United Kingdom, the United States, and other countries, its use has remained low in the United States because of issues of availability and reimbursement.[2,85] Obvious benefits of ABPM include the collection of multiple BP measurements that provide more comprehensive information on BP than is possible with office or home measurements. A key advantage of ABPM over other methods is its ability to identify BP patterns (ie, sustained, white-coat, masked, and nocturnal hypertension, and nondipping or reverse-dipping BP) that cannot be detected with office BP alone (Figure 1). These BP phenotypes are important to recognize because their management and clinical outcomes vary substantially from each other. Table 8

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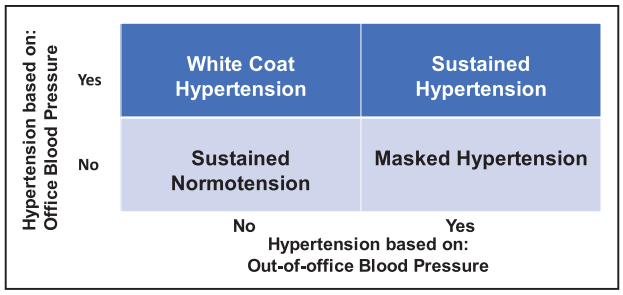


Figure 1. Cross-classification of office and out-of-office hypertension. Out-of-office hypertension is defined on the basis of home blood pressure (BP) monitoring or ambulatory BP monitoring. Reprinted from Pickering et al[86] with permission. Copyright © 2008, Wolters Kluwer Health.

provides guidance on training to conduct ABPM, selection of devices, patient preparation, frequency of BP readings, duration of monitoring, and processing of a recording.

ABPM Devices and Device Selection

Most ABPM devices are automated and programmable and measure BP by the oscillometric method. Some ABPM devices use the auscultatory method and a microphone. Choice of ABPM devices for clinical use in practices or hospitals should be based primarily on independent validation and reliability assessments (see the Protocols for the Validation of BP Monitors section) and quality and ease of use of software for clinical utility. Most ABPM devices marketed and used in the United States have had extensive validation testing performed by independent investigators and published in the peer-reviewed medical literature or posted on validation websites. However, validation occurs at the beginning of a new line of production, and revalidation is often not performed.[87] This is relevant because ABPM devices in clinical settings are often in use for well over a decade. It is advisable that the ABPM devices are regularly serviced for maintenance and calibration to protect against loss of accuracy (see the Device Calibration section).

ABPM Procedures

An overview of ABPM procedures is also provided in Table 8.

Frequency and Number of Readings on ABPM

Most ABPM devices can be programmed to conduct BP measurements at set intervals or to vary reading frequency according to the time of day. Some evidence suggests that an accurate estimate of 24-hour BP can be obtained by readings taken every 60 minutes.[88] A common approach is to obtain BP readings at 15- to 30-minute intervals while the individual is awake (eg, 6 AM–10 PM) and at 30-minute intervals while the individual is asleep (eg, 10 PM–6 AM).[89,90] A more straightforward approach is to obtain BP readings using the same interval between measurements over the entire 24-hour period. Readings more frequent than every 15 minutes should be avoided because they may be disruptive and lead to removal of the ABPM device. The frequency of BP measurements should be accounted for when the mean 24-hour BP is calculated if the interval between readings is different during the day and night.

Criteria for Considering an ABPM Complete

There is no standard for the criteria used to define a complete ABPM recording. Some clinical studies have required ≥80% of planned BP readings in conjunction with at least 1 reading per hour.[91] Less stringent criteria, using either a minimum percentage or number of valid BP readings, have been used in other settings. For example, the UK National Institute for Health and Care Excellence guideline recommends that patients obtain ≥14 daytime readings for an ABPM recording to be considered complete.[92] The 2016 Canadian Hypertension education program guidelines criteria for a successful ABPM include requiring that at least 70% of planned readings are valid, with a minimum of 20 daytime and 7 nighttime readings, while the 2018 European Society of Cardiology/ESH guideline requires 70% of planned readings to be valid.[13a,62] Until other data become available, it is reasonable to follow these criteria for considering an ABPM recording complete.

Identifying Daytime and Nighttime Periods on ABPM

When ABPM is performed, it is highly desirable to consider nighttime BP in addition to daytime BP. Many individuals without high daytime BP have high nighttime BP, which is itself associated with increased CVD and mortality risk.[93] The terms *daytime* and *nighttime* (or *nocturnal*) are often used to refer to when a participant undergoing ABPM is awake and asleep. However, in some studies, daytime and nighttime reflect set time periods.[94,95] Time used to define the daytime and nighttime (or nocturnal) periods can be determined by self-report, fixed time, or, less commonly, actigraphy.[96–98] The self-report and actigraphy-based approaches (using a wrist actigraph device or an ABPM device that has actigraphy capabilities) are used to define the awake and sleep periods. The fixed-time approach uses set intervals to define the daytime and nocturnal periods (eg, nighttime, midnight–6 AM; daytime, 10 AM–8 PM) rather than using actual awake and sleep periods. This approach is intended to omit the sleep-awake transition periods and BP fluctuations during these periods, including the morning BP surge, but does not take into consideration the effect of napping on BP during the daytime.[94,97,99] One study showed higher agreement in daytime and nocturnal BP between self-report and actigraphy than between either self-report and fixed time or fixed time and actigraphy.[100] Self-report is the most pragmatic approach in clinical practice to define sleep and awake periods.

BP Phenotypes Defined With ABPM

White-Coat Hypertension and White-Coat Effect

For many individuals, their BP measured in the office setting is higher than their average BP when measured outside of the office setting. As originally described by Pickering and colleagues,[101] white-coat hypertension is defined as having office BP in the hypertensive range but out-of-office BP not in the hypertensive range in patients not taking antihypertensive medication. Patients taking antihypertensive medication with hypertensive BP levels measured in the office but not outside of the office are referred to as demonstrating a white-coat effect.[1,90] Previously, white-coat hypertension and white-coat effect were based on awake BP or 24-hour BP. Some current

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Table 8. Guidance for Conducting ABPM

Medical staff or provider training
Provide knowledge about the BP measures that can be obtained with ABPM
Provide training in the specialized equipment, techniques, and devices used to conduct ABPM
Provide training to prepare patients for ABPM
Train staff to prepare/initialize the device for a recording
Train staff to fit the device, cuff, and tubing on the patient
Train staff in the ABPM software and downloading of data
Devices and cuffs and equipment
Use validated upper-arm cuff oscillometric devices
Use a cuff that is an appropriate size for the nondominant arm; the nondominant arm is used because movement may interfere with BP measurement
Use new or recharged batteries
Patient preparation and instruction
Provide instruction on what ABPM involves and coping with the procedure
Provide instruction that the ABPM may disrupt sleep
Provide instruction to avoid showering or swimming and not to remove the ABPM device, cuff, and tubing (unless showering or swimming)
Provide instruction for patients to follow their usual daily activities but to keep their body, especially their arm, still during each BP measurement
Provide a brief summary of ABPM procedures to the patient on a card that can be referred to during the procedure
Provide instruction on how to refit the cuff if it migrates from its ideal position
Provide instruction on placing the device on the bed or beneath a pillow during sleep
Provide instruction on how to turn off the device in the event that it is malfunctioning
Provide instruction on filling out a diary to document sleep and awakening times, as well as the time of antihypertensive medication intake, occurrence of symptoms (eg, dizziness), and meals (if requested by provider)
Frequency and number of readings
Every 15–30 min during the 24-h period (48–96 total readings)
Duration of monitoring
Preferred period is 24 h of monitoring
Analyzing readings
There are no strong empirical data on the minimum number of readings needed for defining a complete ABPM. Commonly recommended criteria are ≥20 readings during the daytime period and ≥7 readings during the nighttime period. However, an ABPM recording with fewer daytime and/or nighttime readings may still be valid.
For each period (daytime, nighttime, and 24 h), the average of all readings should be calculated to determine mean daytime BP, mean nighttime BP, and mean 24-h BP, respectively, and other BP measures (eg, dipping).

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

definitions of white-coat hypertension and white-coat effect require awake, 24-hour, and nocturnal BPs not to be in the hypertensive range.[90] Among patients with office BP in the hypertensive range, the prevalence of white-coat hypertension using awake or 24-hour BP to define out-of-office BP is 15% to 30%.[101–103] Studies have shown that a high percentage (30%–40%) of patients taking multiple classes of antihypertensive medication with SBP ≥140 mm Hg or DBP ≥90 mm Hg based on measurements taken in the clinic have the white-coat effect.[104,105] Because white-coat hypertension and the white-coat effect in many cases are attributable to the effect of the observer (eg, clinician or medical staff taking the BP reading), using AOBP in the office setting without an observer present may help lessen the prevalence of these phenotypes.[49] The white-coat effect has been implicated in office uncontrolled hypertension and pseudoresistant hypertension, which may underestimate BP control when it is subsequently assessed by ABPM or HBPM.

Most studies, but not all, have shown that white-coat hypertension by itself confers minimal excess cardiovascular risk.[106–108] In the studies in which white-coat hypertension was associated with a substantially higher risk of CVD events, most of the excess risk may be explained by the presence of other CVD risk factors.[106,109] In patients with white-coat hypertension, it is not clear that antihypertensive drug treatment lowers CVD risk. In a secondary analysis of the Syst-Eur trial (Systolic Hypertension in Europe), participants with white-coat effect did not exhibit a lower rate of CVD events when randomized to active treatment (ie, nitrendipine, with add-on enalapril, hydrochlorothiazide, or both as needed) versus placebo.[110] However, people with white-coat hypertension may progress to sustained hypertension more quickly than people with sustained normotension (ie, nonhypertensive office and out-of-office BPs).[111] Annual follow-up with ABPM (or alternatively HBPM) should be considered for untreated patients with white-coat hypertension to determine whether a transition to sustained hypertension has occurred.[1,112,113]

Figures 2 and 3 show diagnostic algorithms from the 2017 Hypertension Clinical Practice Guidelines for identifying white-coat hypertension and the white-coat effect, respectively.

Masked Hypertension

Masked hypertension, a term coined by Pickering and colleagues in 2002,[114] refers to a mean out-of-office BP in the hypertensive range with BP not in the hypertensive range when measured in the office. Although most definitions of masked hypertension consider daytime or 24-hour BP, the ESH has recommended the incorporation of nighttime BP into the definition of masked hypertension.[90] Therefore, patients with office BP in the normotensive range but with BP in the hypertensive range during the daytime, nighttime, or the 24-hour monitoring period are said to exhibit masked hypertension. The definition of masked hypertension originally applied only to people who were not taking antihypertensive therapy. However, patients taking antihypertensive therapy may also exhibit a "masked effect." The

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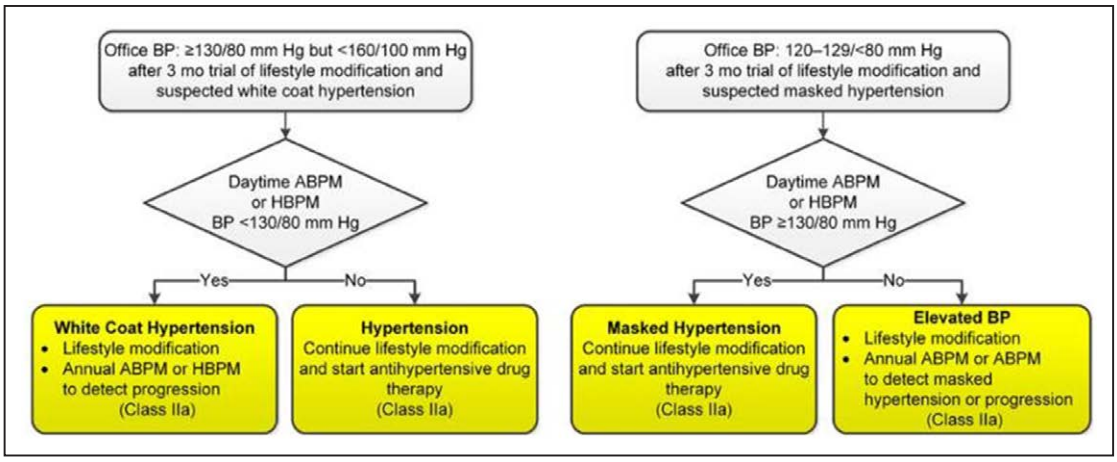


Figure 2. Algorithm to screen for white-coat hypertension and masked hypertension in adults not on drug therapy. ABPM indicates ambulatory blood pressure monitoring; BP, blood pressure; and HBPM, home blood pressure monitoring. Reprinted from Whelton et al[1] with permission. Copyright © 2017, by the American College of Cardiology Foundation and the American Heart Association, Inc.

term *masked uncontrolled hypertension* describes the condition in patients taking antihypertensive medication with office BP in the normotensive range but out-of-office BP in the hypertensive range.[90]

Masked hypertension is present in ≈15% to 30% of the general adult population whose office BP is in the normotensive range (eg, SBP/DBP <140/90 mm Hg).[3] One study estimated that 17 million US adults have masked hypertension.[115]

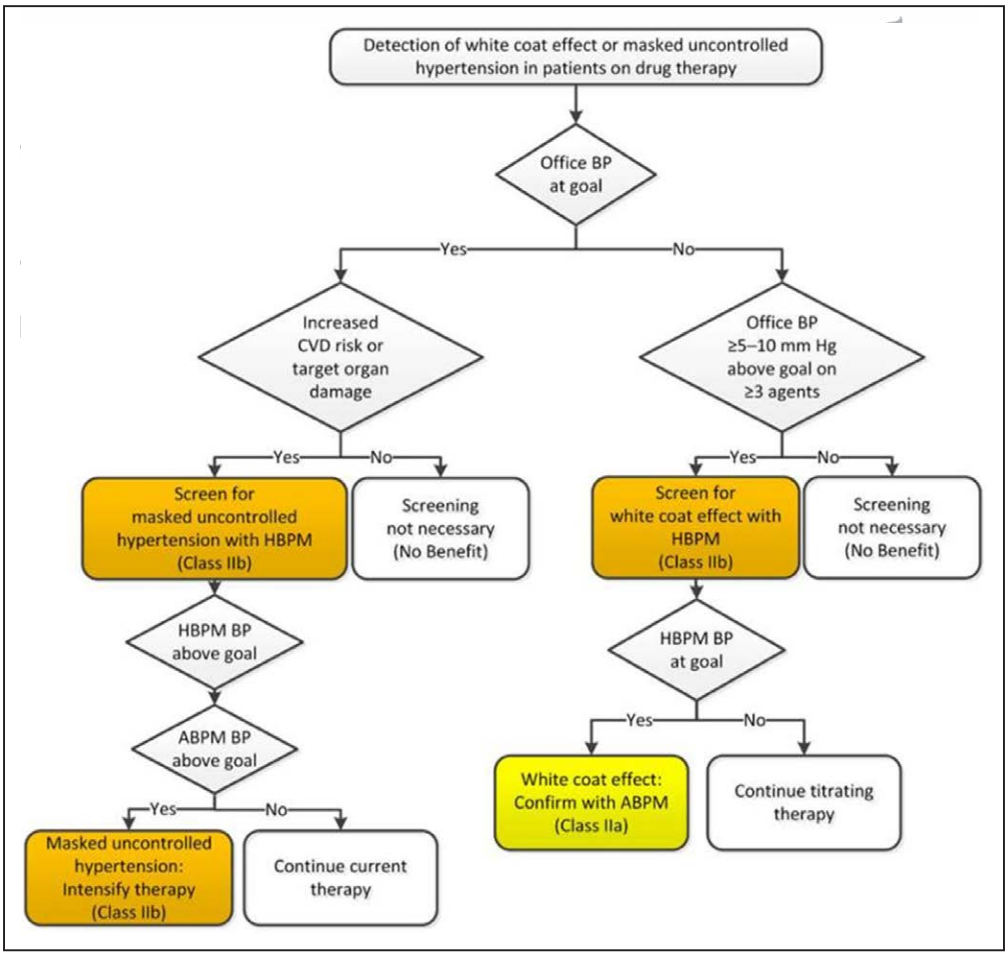


Figure 3. Detection of white-coat effect or masked uncontrolled hypertension in patients on drug therapy. The 2017 American College of Cardiology/American Heart Association blood pressure (BP) guideline used the term *white-coat effect* to refer to adults taking antihypertensive medication with hypertensive-level BP in the office with BP at goal when measured outside of the office. ABPM indicates ambulatory BP monitoring; CVD, cardiovascular disease; and HBPM, home BP monitoring. Reprinted from Whelton et al[1] with permission. Copyright © 2017, by the American College of Cardiology Foundation and the American Heart Association, Inc.

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However, when nocturnal hypertension is included in the definition of masked hypertension, its prevalence exceeded 50% in blacks in the JHS (Jackson Heart Study).[116] Studies have shown that a fairly high proportion of those whose office SBP/DBP is within 20/10 mm Hg of the threshold for office-based hypertension have masked hypertension.[117–119]

Masked hypertension is more common among certain subgroups of the population, including those with diabetes mellitus, chronic kidney disease, and obstructive sleep apnea.[120–123] It has been associated with target-organ damage (left ventricular hypertrophy and carotid plaque) on an order of magnitude approaching that associated with sustained hypertension (ie, BP in the hypertensive range in both the office and out-of-office environments).[124,125] Multiple cohort studies and meta-analyses have also reported that masked hypertension is associated with an incidence of CVD events similar to that seen among their counterparts with sustained hypertension.[107,126–128] The CVD risk profile in adults with masked uncontrolled hypertension approaches that of their counterparts with uncontrolled hypertension in both the office and out-of-office setting.[128,129] Although it might be that untreated adults with masked hypertension would benefit from pharmacological treatment or lifestyle changes, no randomized controlled trial data testing the benefit of antihypertensive drug treatment on either masked hypertension or masked uncontrolled hypertension are available.

Figures 2 and 3 show diagnostic algorithms from the 2017 Hypertension Clinical Practice Guidelines for identifying masked hypertension and masked uncontrolled hypertension, respectively.

Nocturnal Hypertension

Nocturnal hypertension is characterized by hypertensive BP during sleep. ABPM is the primary method to detect this phenotype. Nocturnal hypertension has been estimated to affect >20% of whites and 40% of blacks.[95,130] The prevalence of nocturnal hypertension is also higher among adults with diabetes mellitus and chronic kidney disease. ABPM has been reported to affect sleep quality and result in impaired sleep efficiency, but the degree to which high nocturnal BP is the result of wearing an ABPM device is unclear. Multiple studies, including a large meta-analysis, have reported that higher BP during sleep is associated with an increased risk for CVD events independently of awake BP.[94,131–135] Scant data exist correlating nocturnal BP and CVD outcomes in US and black populations. There is 1 report that nighttime versus morning dosing of antihypertensive medication results in lower nocturnal BP and reduced CVD outcomes.[136] However, another study using modest doses of short-acting antihypertensive agents found no effect of nighttime versus morning dosing on nocturnal or 24-hour BP, and this approach resulted in higher daytime BP.[137]

Nondipping and Reverse-Dipping BP

Normally, BP decreases during sleep, which has been called nocturnal dipping. Nocturnal dipping occurs in response to a decline in sympathetic nervous system activity.[138] The degree of BP dipping has been defined as asleep BP relative to awake BP (ie, 1 minus the ratio of mean asleep to mean awake BP) and categorized in 2 groupings (dipping [≥10% decline in BP from awake to asleep] and nondipping [<10% decline in BP]) or 4 groupings (extreme dipping [≥20% decline in BP], dipping [10%–20% decline in BP], nondipping [0% to <10% decline in BP], and reverse dipping [sleep BP higher than awake BP]). Between 10% and 30% of whites and up to 65% of blacks have a nondipping or reverse-dipping BP phenotype.[95,132,139,140] Compared with dippers, those with nondipping or reverse-dipping BP patterns are reported to have an increased risk of cardiovascular target-organ damage (increased left ventricular hypertrophy and carotid intima-media thickness) and CVD outcomes, although some studies suggest that nondipping BP status adds little predictive value for CVD risk over 24-hour mean BP.[94,132,134,139,141–143] One study reported an increased risk for stroke with extreme dipping versus normal dipping BP, whereas extreme dipping was not associated with increased CVD risk in other studies.[94,144,145]

Morning BP Surge

CVD events, including myocardial infarction and stroke, frequently occur during the period between 6 AM and noon.[146,147] This period coincides with the rapid rise in BP that occurs when people awaken. This has led to the hypothesis that the rise in BP on awakening is associated with increased CVD risk. The morning BP surge has been defined as the difference between the average BP during the 2 hours after awakening and either the mean during the 2 hours before awakening or the mean of the lowest nighttime BP and the 2 readings surrounding the lowest reading. Some reports associate an exaggerated morning rise in BP on ABPM with increased risk of CVD events.[148–150] However, how morning surge should be defined and whether the morning surge is associated with an increased risk for adverse outcomes are unclear.[151]

Reproducibility of Mean BP on ABPM and BP Phenotypes Defined With ABPM

Mean awake, sleep, and 24-hour BPs on ABPM have had reasonably good short-term reproducibility in most, although not all, studies.[152–155] Circadian BP patterns, however, have only modest reproducibility: Nondipping BP, isolated nocturnal hypertension (ie, normotensive office BP and awake BP with nocturnal BP in the hypertensive range), and isolated daytime hypertension (ie, normotensive office BP and nocturnal BP and awake BP in the hypertensive range) have demonstrated poor reproducibility.[156] The reproducibility of white-coat and masked hypertension is fair to moderate over the short term.[157,158] When borderline BP values are present, the ESH recommends repeating the ABPM procedure to confirm the diagnosis of white-coat and masked hypertension.[13a]

Clinical Indications for ABPM

In 2001, Medicare approved reimbursement for the conduct of ABPM to evaluate the presence of white-coat hypertension. Since that time, several scientific statements and position articles have recommended using ABPM to confirm the diagnosis of hypertension and to rule out the presence of white-coat hypertension in untreated individuals to prevent unnecessary prescription of antihypertensive medications in these

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individuals.[2,13a,90,159–162] In 2011, in part on the basis of a cost-effectiveness analysis, the UK National Institute for Health and Care Excellence recommended that out-of-office BP measurement be performed to confirm the diagnosis of hypertension in individuals presenting with office hypertension.[160,163,164] In 2015, the US Preventive Services Task Force also recommended that out-of-office BP measurement be performed to confirm the diagnosis of hypertension when BP measurements made in the office setting are in the hypertensive range.[2] The UK National Institute for Health and Care Excellence and the US Preventive Services Task Force concluded that ABPM is often considered the reference standard for diagnosing hypertension.[2,92] The increasing recognition that the CVD risk associated with masked hypertension is similar to that of sustained hypertension has led the 2018 ESH/European Society of Cardiology guideline and 2017 Hypertension Clinical Practice Guidelines to also recommend screening for masked hypertension.[1,13a]

Indications for ABPM include the following:

- Assessing the presence of white-coat hypertension or masked hypertension
- Monitoring of antihypertensive medication efficacy in treated patients.
  - Assessing white-coat effect
  - Assessing masked uncontrolled hypertension
- Assessing the presence of nocturnal hypertension
- Evaluation of postural, postprandial, and drug-induced hypotension
- Assessing hypotension from autonomic dysfunction, which typically also requires monitoring during sleep for supine hypertension

Home BP Monitoring

Overview

Although ABPM is recommended as the preferred out-of-office BP assessment method in some BP guidelines, it requires additional clinic visits and is not suitable for or well tolerated by some patients.[1,2,92] In addition to ABPM, HBPM is a modality for assessing out-of-office BP. *HBPM* refers to individuals having their BP measured at home. The term *HBPM* is not necessarily synonymous with self-measured BP because some prior HBPM studies have had participants' BP measured at home by an observer.[165] Furthermore, in addition to BP measured at home, *self-measured BP* can refer to individuals taking their own BP outside of their home (eg, at work, a pharmacy, or a kiosk). Here, we use the term *HBPM* to refer to individuals conducting the self-measurement of their own BP in their home. In contrast to ABPM, HBPM is better tolerated, more widely available, and associated with lower cost.[4,166] Several studies have shown that BP on HBPM maintains a stronger association with CVD risk than office BP.[167–169] HBPM also can be used to identify patients with white-coat hypertension and masked hypertension, and it can be used more easily to monitor BP levels over time.

An HBPM device that assesses BP during sleep has recently become available in the United States. Preliminary data suggest that HBPM devices that assess sleep BP give values

Table 9. Guidance for Conducting HBPM

Patient training provided by healthcare staff or providers
Provide information about hypertension diagnosis and treatment
Provide information on the proper selection of a device
Provide instruction on how patients can measure their own BP (if possible, demonstrate the procedure)
Provide instruction that the HBPM device and BP readings should be brought to healthcare visits
Provide education that individual BP readings may vary greatly (high and low) across the monitoring period
Preferred devices and cuffs
Use an upper-arm cuff oscillometric device that has been validated
Use a device that is able to automatically store all readings
Use a device that can print results or can send BP values electronically to the healthcare provider
Use a cuff that is appropriately sized for the patient's arm circumference
Best practices for the patient
Preparation
Have an empty bladder
Rest quietly in seated position for at least 5 min
Do not talk or text
Position
Sit with back supported
Keep both feet flat on the floor
Legs should not be crossed
BP cuff should be placed on a bare arm (not over clothes)
BP cuff should be placed directly above the antecubital fossa (bend of the arm)
Center of the bladder of the cuff (commonly marked on the cuff by the manufacturer) should be placed over the arterial pulsation of the patient's bare upper arm
Cuff should be pulled taut, with comparable tightness at the top and bottom edges of the cuff, around the bare upper arm
The arm with the cuff should be supported on a flat surface such as a table
Number of readings
Take 2 readings at least 1 min apart in the morning before taking antihypertensive medications and 2 readings at least 1 min apart in the evening before going to bed
Duration of monitoring
Preferred monitoring period is ≥7 d (ie, 28 readings or more scheduled readings); a minimum period of 3 d (ie, 12 readings) may be sufficient, ideally in the period immediately before the next appointment with provider
Monitoring conducted over consecutive days is ideal; however, readings taken on nonconsecutive days may also provide valid data
Analyzing readings
For each monitoring period, the average of all readings should be obtained. Some guidelines and scientific statements recommend excluding the first day of readings. If the first day of readings is excluded, the minimum and preferred periods of HBPM should be 4 and 8 d, respectively.

BP indicates blood pressure; and HBPM, home blood pressure monitoring. HBPM tools and resources can be found online.[175]

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similar to those obtained by ABPM.[170] Some studies have shown that the use of HBPM is associated with a reduction in clinical/therapeutic inertia.[171–173] Although concern has been raised about patient recall or written logs of BP, this issue can be addressed by using HBPM devices with built-in memory that automatically stores readings and having patients bring their devices to clinic visits.[92,161,166,174] Many new HBPM devices have this memory-storing capability with minimal additional cost.

HBPM Devices and Device Selection

- Similar to ABPM devices, the majority of HBPM devices are oscillometric, the preferred measurement method for clinical practice.
- Healthcare providers should advise their patients to use only upper-arm cuff oscillometric devices that have successfully passed validation protocols (see the Protocols for the Validation of BP Monitors section) because many nonvalidated devices do not provide accurate measurements of BP.
- A list of validated HBPM devices can be found on the British and Irish Hypertension Society and Dabl Educational Trust websites.[174a,174b]
- Among the validated HBPM devices, there are now several options to consider.
  - The simplest devices require the user to push a button to initiate a reading, which is then displayed after the reading is taken.
  - Some devices can be programmed to take multiple readings with the option of specifying the interval between readings (eg, 1 or 2 minutes).
  - Only devices that can store readings, along with the dates/times they were taken, that can be displayed on the device screen, printed, or transmitted to their healthcare provider should be recommended to patients.
  - Some devices can detect the presence of atrial fibrillation (AF).

HBPM Procedures

An overview of HBPM procedures to be used by medical staff for patient training is provided in Table 9.

Frequency, Number of Readings, and Number of Days of HBPM

The 2008 AHA scientific statement on the use and reimbursement for HBPM recommended that diagnosis of hypertension with HBPM should be based on 2 measurements taken in the morning and 2 taken at night over a preferred period of 7 days (ie, 28 scheduled readings).[166] A minimum of 3 days (ie, 12 readings) for estimating mean home BP has also been recommended because the mean of morning and evening measurements obtained over this period may provide a sufficiently accurate assessment of home BP.[176,177] BP readings obtained on the first day of HBPM are sometimes elevated, and some have recommended that these measurements be discarded.[177,178] If this approach is taken, then an additional day of readings should be obtained, with a minimum and preferred period of HBPM being 4 and 8 days, respectively. It is reasonable to ask patients to obtain more measurements over a longer time period (eg, before an office visit or after an antihypertensive medication change).[179]

BP Phenotypes Defined With HBPM

Similar to ABPM, HBPM can be used to identify white-coat hypertension, white-coat effect, masked hypertension, and masked uncontrolled hypertension, phenotypes described in the White-Coat Hypertension and White-Coat Effect section and the Masked Hypertension section. In a pooled analysis of 5 population-based cohorts with participants who completed HBPM (n=5007 and n=1451 not taking and taking antihypertensive medication, respectively), white-coat hypertension was associated with an increased risk for CVD events after multivariable adjustment (hazard ratio, 1.42 [95% CI, 1.06–1.91]), whereas no association was present between white-coat effect and CVD events (hazard ratio, 1.16 [95% CI, 0.79–1.72]).[180] White-coat hypertension and white-coat effect were not associated with all-cause mortality. In this same pooled data set, participants with masked hypertension and masked uncontrolled hypertension experienced an increased risk for CVD events after multivariable adjustment (hazard ratio, 1.55 [95% CI, 1.12–2.14] for masked hypertension; and hazard ratio, 1.76 [95% CI, 1.23–2.53] for masked uncontrolled hypertension).[180] Figures 2 and 3 show diagnostic algorithms from the 2017 Hypertension Clinical Practice Guidelines for using HBPM to identify white-coat and masked hypertension in untreated and treated individuals, respectively.

Reproducibility of Mean BP on HBPM and BP Phenotypes Defined With HBPM

The reproducibility of mean BP on HBPM is high. The test-retest correlations on HBPM have ranged from 0.70 to 0.84 for mean SBP and from 0.56 to 0.83 for mean DBP.[78,181–183] The SD of difference scores ranged from 7.7 to 10.7 mm Hg and was substantially lower than the SD of difference score for SBP measured in the office setting in those studies that reported both. The reproducibility of DBP on HBPM was substantially better (higher test-retest correlation, lower SD of difference score) than for DBP measured in the office in 1 study, worse in a second study, and not reported in 2 other studies.[78,181–183] The test-retest agreement for masked hypertension and white-coat hypertension on HBPM is lower because it depends on the reproducibility of both office- and HBPM-defined hypertension.[157,184]

Clinical Indications for the Use of HBPM

Indications for HBPM include the following:

- Assessing for the presence of white-coat hypertension or masked hypertension
- Monitoring of antihypertensive medication efficacy in treated patients
  - Assessing for white-coat effect
  - Assessing for masked uncontrolled hypertension

In addition to its utility in more accurately assessing risk and BP control, use of HBPM is associated with improvement in BP control when it is accompanied by patient feedback, counseling, and other adherence strategies. It is important to stress that the benefit of HBPM on BP control does not occur in isolation. A systematic review and individual patient-level

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Table 10. Conceptual Differences Between ABPM and HBPM

BP is measured over different lengths of time
ABPM measures BP typically over a 24-h period
HBPM measures BP typically every day for several days to weeks
Each measures BP over a different time of day
ABPM measures BP typically during the awake and sleep periods
HBPM measures BP typically during the awake period only*
Each measures BP under different ecological conditions
ABPM measures BP while a person undergoes his/her regular daily activities, including sleep
HBPM measures BP during a period of rest in a seated position
Miscellaneous
Patients are typically not shown BP readings on ABPM, whereas they are usually aware of HBPM readings
BP measurements on ABPM are obtained automatically with the device, whereas BP measurements are triggered manually by patients on HBPM

ABPM indicates ambulatory blood pressure monitoring; BP, blood pressure; and HBPM, home blood pressure monitoring.

*Some newer HBPM devices measure BP during sleep.

data meta-analysis suggested that HBPM was associated with greater BP control when used in conjunction with web/telephone feedback with or without education and with counseling whether in person or by telephone.[185] This study confirmed the results of a prior systematic review and meta-analysis that examined HBPM with and without one-on-one counseling, remote telemonitoring, and educational classes.[186] HBPM is effective in improving BP control when used in conjunction with other adherence-enhancing strategies such as the use of nurse case managers,[187,188] electronic reminders,[189] and behavioral management teams.[190] Some devices are equipped with telemonitoring capabilities such that home BP data are transmitted wirelessly to nurse case managers or physicians' offices to facilitate behavior-enhancing strategies; this strategy has also been shown to be effective in improving hypertension control.[191] Two systematic reviews of existing clinical trials testing interventions to improve medication adherence demonstrated that patients randomized to HBPM had greater improvement in medication adherence compared with those without it.[192,193] What is not clear, however, particularly from the results from a recent systematic review, is the effect of HBPM on other lifestyle behaviors, including diet and physical activity.[193]

Contrasting ABPM and HBPM

Conceptual Differences Between ABPM and HBPM

Despite the associations between higher BP on both ABPM and HBPM with increased CVD risk, there are important conceptual differences between these 2 measurement methods (Table 10).[4] These differences may explain why there is only a moderate correlation between BP on ABPM and HBPM in detecting and differentiating BP phenotypes.[176] A systematic review found insufficient evidence that ABPM or HBPM was superior to the other for predicting CVD risk.[194] Guidelines, scientific statements, and position articles most commonly recommend ABPM over HBPM to confirm the diagnosis of hypertension and to exclude white-coat hypertension.[13a,159–162] This may reflect the fact that more studies used ABPM than HBPM, as well as other features, including the ability for ABPM to detect nocturnal hypertension.[113] As a result of the greater number of studies supporting ABPM over HBPM, the preferred out-of-clinic BP measurement for the diagnosis and treatment of hypertension is ABPM. HBPM is an acceptable alternative if ABPM is not available or not tolerated by the patient.

Challenges in Performing ABPM and HBPM

There are several challenges to performing ABPM and HBPM in clinical practice in the United States.[195] ABPM is not widely available in primary care settings; white-coat hypertension is often the only indication for which ABPM will be reimbursed; and the amount of reimbursement is currently low.[196] In addition, ABPM may not be well tolerated by some patients, particularly at night.[197,198] There are also challenges associated with HBPM. Many HBPM devices on the market have not been validated; they are often not reimbursed by insurance companies; and some devices do not automatically record BP measurements, leading to reliance on the patients to document their readings.[166,199] A sizable percentage of patients do not report their BP accurately.[200] In addition, HBPM may lead to preoccupation with one's BP, which may lead to anxiety.[201–203]

Normative Values for ABPM and HBPM

Efforts to identify an appropriate threshold for defining hypertension on ABPM have focused on mean awake, sleep, and 24-hour BP levels and awake BP levels for HBPM. Three main approaches have been used in prior studies to determine normative BP values for ABPM and HBPM: the distribution-derived approach, the regression-derived approach, and the

Table 11. HBPM and ABPM Levels Corresponding to Office BP Levels

Office BP, mm Hg	HBPM, mm Hg	Daytime ABPM, mm Hg	Nighttime ABPM, mm Hg	24-h ABPM, mm Hg
120/80	120/80	120/80	100/65	115/75
130/80	130/80	130/80	110/65	125/75
140/90	135/85	135/85	120/70	130/80
160/100	145/90	145/90	140/85	145/90

Clinic BP levels in this table are based on measurements obtained with auscultation or a semiautomated oscillometric device. ABPM indicates ambulatory blood pressure monitoring; BP, blood pressure; and HBPM, home blood pressure monitoring.

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outcome-derived approach. The distribution-derived approach identifies percentiles (eg, 90th, 95th, and 99th) of the BP distribution on ABPM and HBPM.[204,205] The regression-derived approach identifies BP levels on ABPM and HBPM that correspond to specific office BP levels (eg, 120/80, 130/80, and 140/90 mm Hg).[206,207] The outcome-derived approach identifies the threshold for BP on ABPM and HBPM that corresponds to the same risk for a CVD outcome as a prespecified office BP threshold (eg, 130/80 mm Hg).[208,209] There have been some differences in the ABPM and HBPM thresholds identified with these 3 methods, but basing thresholds on outcomes seems reasonable. Most normative data for BP on ABPM and HBPM have been derived from European, Asian, and South American populations.[204,206–210] Data from the JHS provide the only normative BP data in the United States for ABPM, albeit only for blacks.[211] With the outcome-derived approach, daytime, 24-hour, and nighttime thresholds for defining hypertensive SBP levels were higher in blacks compared with those currently recommended in scientific statements.[211] However, normative data from the JHS were based on only 165 events (80 CVD events and 85 all-cause deaths). In the 2017 Hypertension Clinical Practice Guidelines, BP levels on ABPM and HBPM were provided to correspond with various levels of office BP measured with auscultation or a semiautomated oscillometric device (Table 11).[1] These BP levels on ABPM and HBPM were determined from studies that used the outcomes-derived approach in conjunction with the thresholds for office SBP/DBP of 140/90 mm Hg from prior scientific statements.[13a,208,212–215] It is worth noting that the ABPM and HBPM levels were not derived from randomized trials showing the benefit or harm associated with particular BP thresholds.

Special BP Measurement Techniques

Overview

The standard location for BP measurement is the upper arm. Alternative sites to measure BP include the wrist and finger. Although BP can be measured on the ankle to identify lower-extremity disease, the current scientific statement is focused on measuring BP to identify hypertension. Information on the diagnosis of lower-extremity disease can be found elsewhere.[216]

Finger Cuff

Arterial BP measurement in the finger is based on the volume-clamp method. A cuff is placed around the finger and inflated to a pressure equal to the pressure in the artery until the artery is about to collapse and the transmural pressure is almost at zero. The cuff pressure is dynamically adjusted by a servomechanism system, which monitors the size of the digital arteries by photoplethysmography. Several systems have been validated in clinical studies.[217,218] However, the reproducibility of the finger-cuff method depends on several factors, including the cuff application, position of the finger relative to the heart, and background noise. Finger BP monitors often provide values that are lower than those obtained in healthcare providers' offices. Therefore, BP values from finger monitoring should not be used for the diagnosis of hypertension or for the management of patients.

Wrist Monitors

Wrist monitors have become popular because of their ease of use and their ability to obtain a measurement in individuals who are obese and have very large upper arms. Only in the past decade or so have manufacturers been able to develop wrist devices that could pass the validation protocols used to evaluate the accuracy of BP devices. Although arguably more convenient, there are 2 important limitations of wrist devices, even those that are able to measure BP accurately. First, BP can be measured only if the sensor of the monitor is directly over the radial artery, and there is a tendency for the device not to maintain the proper positioning on the wrist.[219] Wrist flexion may enhance the problem of obtaining the optimal position. Second, an accurate reading is obtained only if the wrist is at heart level; readings will be too high or too low if the wrist is below or above heart level, respectively.[220,221] Some users prefer to measure BP while sitting on a chair with their arm on a desk, which may be an easier position, especially for older adults.[219,222,223] Thus, although convenient for the consumer, wrist monitors provide many challenges with precision, and strong reservations have been raised about their use in routine clinical practice, unless measurements in the upper arm are not feasible.[224,225]

Ultrasonography Techniques

Noninvasive local BP assessment in the arteries has been used in many clinical applications for diagnosing hypertension and monitoring BP control for people with an arteriovenous fistula or morbid obesity.[226] These devices measure the absolute local BP waveforms by applying an ultrasound transducer to the skin above an artery. This indirect method of BP measurement is frequently used in patients with faint Korotkoff sounds and in individuals with compromised peripheral access (ie, arteriovenous fistulas in hemodialysis patients).

Tonometry

Applanation tonometry provides a noninvasive, reproducible, and accurate representation of the aortic pressure waveform and an assessment of the central pulse pressure waveform.[226–228] Radial artery applanation tonometry is performed by placing a handheld tonometer (strain-gauge pressure sensor) over the radial artery and applying mild pressure to partially flatten the artery. The radial artery pressure is then transmitted from the vessel to the sensor (strain gauge) and is recorded digitally. A mathematical formula using Fourier analysis permits calculation of central pressure indexes from a peripheral brachial BP and concomitant recording of a pulse pressure wave. SBP and DBP are estimated from the shape of the waveform. A major drawback of this technique is that most devices are operator dependent, require a trained technician and calibration of peripheral BP recordings, and are cumbersome in clinical practice.[224,226,228,229]

Smartphone Technology

Mobile health technologies may potentially be an effective means of providing health information, support, and management strategies to promote hypertension self-management. Several apps have been developed to measure BP. However, validation studies for most smartphone-based BP measurement techniques have not been conducted. To date, mobile

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health BP monitors have shown poor accuracy compared with oscillometric readings.[230–232]

Wearable Sensors and Cuffless BP Monitors

With an increased interest in personal health and access to technology, there has been a new trend in the development of wearable devices that can promote a healthy lifestyle. One wrist-based method estimates BP from the pulse transit time.[221] The device can also monitor heart rate using an ECG and can measure blood oxygenation. This system uses Bluetooth for wireless transmission of BP. Another approach for noninvasive BP being tested is called subcutaneous tissue pressure equilibrium. It is based on the principle of observing radial skin dynamics with the radial artery under atmospheric pressure.[233] Although current noninvasive techniques for cuffless BP monitoring have demonstrated substantial advances, the lack of accuracy and calibration issues limit their current utility.[233,234]

BP Measurement in Other Settings

Pharmacist-Measured BP

Because a substantial proportion of adults with hypertension remain undetected, undertreated, or with poorly controlled BP, new models of care are being sought to improve clinical outcomes.[235,236] BP monitoring could be an integral part of a pharmacist-based intervention for the management of hypertension.[237–239] Pharmacy-based BP measurements may be an acceptable alternative to assessing daytime BP on ABPM or HBPM, especially in situations when ABPM and HBPM are not feasible.[240] Current evidence suggests that BP measurement in the pharmacy is not likely associated with a substantial white-coat effect, but more studies are needed before this is recommended as a substitute for ABPM or HBPM.[241–244] A critical component of BP measured by pharmacists is training/retraining and device validation/calibration.

BP Kiosks

Kiosks are stations where BP is assessed by a device that is triggered by the individual desiring the measurement in the absence of a healthcare professional.[245] Kiosk measurements, which are a form of self-measured BP, can be useful, especially for BP screening, as long as the device is appropriately validated and calibrated. Kiosks should be located in a setting amenable to achieving accurate BP readings (ie, a quiet, comfortable place), and instructions should be provided so that individuals can take a valid reading and understand their BP values.[245] It should be recognized that most kiosks have only a single cuff size that is too small for most US adults, and some do not have a back support.[246] Despite being cleared for use by the US Food and Drug Administration, many BP kiosks have not been validated according to accepted protocols.[247,248] In addition, there are few data on the reproducibility of or normality thresholds for BP measured at kiosks.

Use in the Acute Care of Patients

There is little, if any, evidence available on the validation of BP measurements obtained in the acute care setting. The majority of critically ill patients with hemodynamic instability or requiring parenteral cardiovascular drug therapy are fitted with an intra-arterial catheter that provides an invasive, direct, and continuous BP recording. Intra-arterial BP measurements are preferred over noninvasive measurements when critical clinical decisions are required. However, in hemodynamically stable patients, valuable information can be obtained with oscillometric devices, arterial tonometry, and other newer noninvasive techniques.[249] Further investigation is required to validate the newer methods of BP measurement in the acute setting.

BP Measurement Considerations in Special Populations

Children

Current recommendations suggest that BP be measured annually for children and adolescents 3 to 17 years of age.[250] High-risk children and adolescents, including those who are obese (body mass index ≥95th percentile), those who have diabetes mellitus, kidney disease, or aortic arch obstruction or coarctation, and those taking medications known to increase BP, should have BP measured at every healthcare encounter.[250] Children <3 years of age who are at high risk for hypertension should have their BP measured at well-child care visits.[250] As in adults, oscillometric devices are becoming more commonly used in the pediatric population.[34] However, it should be noted that few oscillometric devices have been validated in children, and most normative BP data in children and adolescents were obtained with the auscultatory approach. Oscillometric devices cannot distinguish between Korotkoff phases 4 and 5 for DBP, with phase 5 having been most commonly used as the reference DBP in children and adolescents in prior validation studies.[251] A recent collaboration statement from the Association for the Advancement of Medical Instrumentation, ESH, and International Organization for Standardization recommends using the Korotkoff phase 5 for validating BP measuring devices.[24] If an auscultatory device is used, the fifth Korotkoff sound is generally accepted as representing DBP. No large studies of wrist monitors have been conducted in children, so these devices cannot be recommended for pediatric patients.

In children, BP should be taken in the right arm because normative values were obtained in the right arm, unless the child has atypical aortic arch anatomy such as right aortic arch with aortic coarctation or left aortic arch with aberrant right subclavian artery.[250] If the initial BP is elevated (≥90th percentile for sex, age, and height), providers should perform 2 additional oscillometric or auscultatory BP measurements. If auscultation is used, the average measurement should be used to define the BP category. Alternatively, if the oscillometric method is used, 2 measurements should be obtained and averaged to define the BP category. In addition, a leg BP should be obtained while the patient is supine for all hypertensive pediatric patients to rule out coarctation of the aorta.[250] If the leg BP values are >10 mm Hg lower than the arm BP, additional investigation is warranted. The use of an average of multiple measurements from >1 visit in childhood is critical because BP may vary considerably as a result of a variety of factors, including anxiety, medication use (eg, decongestants and stimulants), and greater visit-to-visit BP variability in measurements across visits.

Following a proper BP measurement technique and using a validated device are essential. This technique is illustrated in

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an American Academy of Pediatrics video.[252] Given the usually lower BP levels and smaller arm sizes in children and adolescents compared with adults, oscillometric devices need to be validated for use in this population.[24,251] BP should be obtained only after at least 5 minutes of rest with the patient seated with feet flat on the floor, back supported, and arm at heart level. One notable exception is the neonate, for whom BP should be obtained while the patient is supine to be consistent with the methods used to develop normative data in this age group.[253] Similar to adults, an appropriately sized cuff should be used. However, many studies have documented a lack of availability of appropriately sized cuffs in both inpatient and outpatient pediatric settings, thus increasing the risk for inaccurate BP classification.[254–257] ABPM can also be successfully performed in children and adolescents and is recommended to confirm the presence of hypertension in children and adolescents with elevated BP for 1 year or stage 1 hypertension over 3 office visits.[250] Although home BP may be more reproducible than office BP for children and adolescents, few devices have been validated; only 1 large European study provides normative values on HBPM, and they differ from both office and ambulatory levels.[258] Daytime BP on ABPM is often higher than home BP in children, possibly because of increased physical activity.[259] There are also limited data on the use of school-based measurement of BP in children. Although this approach is useful for screening, it has limitations in making the diagnosis of hypertension.[260]

Pregnancy

Hypertension complicates nearly 10% of all pregnancies and is associated with adverse maternal and fetal outcomes.[261,262] Mercury sphygmomanometry has been the gold standard for recording BP in pregnant women.[263–266] However, aneroid devices have been validated for use in pregnant women. If an oscillometric device is to be used, one that has been validated in pregnant women should be selected. BP should be measured in the seated position either before pregnancy or early in pregnancy to avoid missing chronic hypertension. Although some studies have shown a drop in BP in the left lateral recumbent position, others have not.[267,268] Therefore, current guidelines allow this position for monitoring BP during labor if necessary.[5] In some pregnant women, a large interarm BP difference is present.[269] If this occurs, the arm with the higher values should be used consistently. As with other adults, Korotkoff phase 5 should be used as DBP. ABPM and HPBM may be helpful for out-of-office BP measurement in pregnancy. However, many devices that have been validated in men and nonpregnant women have not been validated in pregnant women, and separate validation of BP-measuring devices in this population should be performed.[264,270,271] A systematic review of BP devices validated in pregnancy has recently been published.[272]

Obese Patients

The choice of an appropriate cuff and bladder size to compress the brachial artery is an essential prerequisite for accurate BP measurement in obese patients.[273,274] With the rising rate of obesity, there has been an increase in the number of individuals with an arm circumference >50 cm.[275] Some data show that an extra-large cuff, frequently referred to as a thigh cuff, can be used to obtain an accurate brachial measurement of BP.[276] However, studies on the validity of using an extra-large cuff to measure BP in obese adults are limited. If an extra-large cuff does not fit, BP may be measured on the wrist. A meta-analysis of adults who were obese reported a sensitivity of 97% and specificity of 85% for identifying hypertension when BP measured in the upper arm was compared with the gold standard of intra-arterial measurements.[277] With upper-arm BP as the gold standard, wrist measurements had better test characteristics (ie, sensitivity and specificity) for diagnosing hypertension compared with BP measurements taken on the forearm or finger.[277] Another cuffing issue affecting BP accuracy is that most obese patients have arms that are tronco-conical; therefore, a cone-shaped cuff should be selected to provide a more accurate estimation of BP.[278,279] The traditional auscultatory method, listening for Korotkoff sounds over the radial artery, or detecting the SBP with a Doppler probe should be used when measuring BP over the brachial artery is not possible.

Older Individuals

With advancing age, there is increased arterial stiffness with reductions in arterial compliance and increased pulse pressure.[280] In addition, because of impaired baroreceptor sensitivity, older patients with hypertension can have exaggerated orthostatic hypotension, which can lead to syncope and falls, as well as increases in cardiovascular morbidity and mortality.[281,282] Older individuals are also more likely to have white-coat hypertension and pseudohypertension (defined in the Pseudohypertension section). In the office setting, BP should be measured in duplicate while the patient is seated, in the standing position immediately after rising, and again after 1 to 2 minutes to assess for potential postural hypotension. Up to a 3-minute wait between rising and measuring BP is suggested in some guidelines.[283,284] However, 1 study found the strongest association between BP measured within 1 minute of rising, versus after 1 minute, and history of dizziness and future risk for fractures, syncope, and mortality.[285] Hypotensive symptoms are more commonly noticed by patients on arising in the morning, in the postprandial state, and when standing up quickly. ABPM may be helpful in older patients for whom white-coat hypertension is suspected and can help elucidate some symptoms such as episodic faintness and nocturnal dyspnea. Moreover, nocturnal hypertension and a nondipping BP profile, often present in older individuals, are associated with the development of small vessel brain disease (also known as white matter hyperintensity lesions on brain magnetic resonance imaging), which leads to cognitive decline and difficulties with mobility and is a risk factor for stroke.[286]

Pseudohypertension

Pseudohypertension occurs when the arterial media becomes severely rigid from calcific arteriosclerosis and the BP cuff/bladder has to be at a higher pressure to compress the vessel. Pseudohypertension results in an elevated cuff pressure compared with intra-arterial measurements. The earliest diagnosis

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of pseudohypertension was by the positive Osler sign: when the brachial or radial artery is still palpable distal to a fully inflated BP cuff. However, the Osler maneuver is not a reliable test, and the Osler sign was present in 7.2% of 3387 individuals ≥60 years of age who were screened for SHEP (Systolic Hypertension in the Elderly Program).[287] Patients with pseudohypertension are often overtreated with antihypertensive medication, resulting in postural hypotension and other side effects. Most patients with pseudohypertension have a brachial artery bruit and triphasic BP readings by Doppler.[288] Older patients with a concomitant history of atherosclerotic disease, chronic kidney disease, and diabetes mellitus have the highest risk of developing pseudohypertension. An ankle-brachial index >1.4 suggests the possible presence of noncompressible arteries. Further investigation of pseudohypertension should be considered in this situation. When suspected, an intra-arterial radial artery BP can be obtained for verification.

Patients With Arrhythmias

Almost all of the studies focusing on BP measurement in people with arrhythmias center on AF. The variability in heart rate in AF leads to changes in the amount of blood within the left ventricle at systole, with shorter periods between heartbeats having less filling and lower BP. Intensive BP control after ablation in AF leads to better outcomes.[289] There is a misperception that oscillometric devices cannot obtain a valid estimate of BP for patients with AF. In reality, studies comparing the accuracy of oscillometric devices with standard auscultatory techniques indicate that oscillometric techniques provide a valid SBP, but less so for DBP, assessment in AF.[290] The population with AF is usually older, and the emphasis has been on SBP in this group.[290] Some HBPM or ABPM devices can detect AF.[291] Arrhythmias can often be heard when an auscultatory BP measurement is performed, and oscillometric devices are available that can detect AF.[291,292]

Pulseless Syndromes

Patients with Takayasu arteritis, giant cell arteritis, or severe atherosclerosis and those on long-term hemodialysis with multiple access procedures in the upper extremities may lack detectable brachial pulses, and often neither auscultatory nor oscillometric methods provide accurate BP readings in these circumstances. It may be possible to use an ankle-based BP in the supine position, recognizing that the ankle SBP is usually higher than a simultaneous measurement in the brachial artery as a result of SBP amplification, generally on the order of ≈20 mm Hg.[293] In special circumstances when the carotid artery pressure is known or thought to be normal, retinal arterial pressures can be measured in patients with pulseless syndromes.

Table 12. Validation Protocols for BP Monitoring Devices

	ANSI/AAMI/ISO[312]	BHS[313]	DHL[314]	ESH[39]
Assessment phases, n	1	5	1	1
Required sample size, n patients (paired BPs)	85 (255)	85 (255)	96 (288)	33 (99)
Age requirement, y	>12	Distributed by chance	Defined ages (20–40, 41–70, >70)	≥25
Measurement method, arm sequential	Same arm sequential or simultaneous or opposite arm simultaneous	Same arm sequential	Same arm sequential	Same arm sequential
SBP range, mm Hg	≤100 (>5%) ≥140 (>20%) ≥160 (>5%)	<90 (n>8) 90–129 (n>20) 130–160 (n>20) 161–180 (n>20) >180 (n>8)	20–40 y (≤140/>140; n=12/12) 41–70 y (≤120/121–140/141–160/>160; n=8/16/16/8) >70 y (≤140/>140; n=12/12)	<90–129 (n=10–12) 130–160 (n=10–12) >160–180 (n=10–12)
DBP range, mm Hg	<60 (>5%) >85 (>20%) >100 (>5%)	<60 (n>8) 60–79 (n>20) 80–100 (n>20) 101–110 (n>20) >110 (n>8)	20–40 y (≤90/>90; n=12/12) 41–70 y (≤80/81–90/91–100/>100; n=8/16/16/8) >70 y (≤90/>90; n=12/12)	40–79 (n=10–12) 80–100 (n=10–12) >100–130 (n=10–12)
Specialized populations	Pregnancy, children, infants, cardiac arrhythmias, exercise	Pregnancy, children, elderly, exercise	Pregnancy, diabetes mellitus	Elderly, children, adolescents, pregnancy, obese
Pass/fail criteria	Pass/fail criteria based on mean BP difference and its SD for individual BP readings and for individual subjects	Pass/fail criteria based on absolute BP differences within 5, 10, and 15 mm Hg for individual BP readings and for individual subjects	Overall mean absolute error determination and a point system for paired readings	Pass/fail criteria based on absolute BP differences within 5, 10, and 15 mm Hg for individual BP readings and for individual subjects

AAMI indicates Association for Advancement of Medical Instrumentation; ANSI, American National Standards Institute; BHS, British Hypertension Society; BP, blood pressure; DBP, diastolic blood pressure; DHL, German Hypertension League; ESH, European Society of Hypertension; ISO, International Organization for Standardization; and SBP, systolic blood pressure.

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Table 13. Summary Points From the Scientific Statement on the Measurement of BP in Humans

BP components
Several BP components (SBP and DBP, pulse pressure, mean arterial pressure) are associated with CVD risk.
SBP and DBP levels are used to define hypertension in most guidelines, including the 2017 Hypertension Clinical Practice Guidelines.
BP measure in the office
The auscultatory BP method has been the traditional approach for measuring BP but is increasingly being replaced with the oscillometric method.
Aneroid sphygmomanometers require frequent calibration (every 2–4 wk for handheld devices and every 3–6 mo for wall-mounted devices).
AOBP devices, which can be used with or without staff present (attended and unattended AOBP, respectively), should be considered for use in measuring office BP.
Unattended AOBP has been associated with a lower prevalence of white-coat effect compared with office BP measured through auscultation and reduces the possibility of human error in BP measurement.
Office BP should be measured ≥2 times at each clinic visit.
Training of personnel is crucial for BP measurement, even when AOBP is being used.
24-h ABPM
ABPM is the preferred approach for assessing out-of-office BP.
The main indications for ABPM are to detect white-coat hypertension and masked hypertension.
White-coat hypertension may not be associated with an increased risk for CVD.
Masked hypertension is associated with a risk for CVD approaching that for individuals with sustained hypertension.
Nocturnal hypertension is common among blacks. ABPM is the preferred approach to assess for nocturnal hypertension.
HBPM
HBPM can be used to assess out-of-office BP when ABPM is not available or accepted by the patient. HBPM can be used to detect white-coat hypertension and masked hypertension.
Many HBPM devices available for purchase have not been validated, and only validated devices should be recommended for HBPM.
HBPM by itself has a limited effect on BP control, but it is effective in reducing BP when used in combination with supportive interventions (eg, web/telephone feedback).
Patients should be encouraged to use HBPM devices that automatically store BP readings in memory or transmit BP readings to a healthcare provider.
Contrasting ABPM and HBPM
ABPM is conducted for 24 h; HBPM typically involves measurements over a week.
ABPM measures BP while a person is awake and asleep; HBPM typically measures awake BP only.
ABPM is conducted while a person goes about his/her daily activities; HBPM is conducted while a person is seated and resting.
Special BP measurement techniques
Devices that measure BP at the wrist have been validated, but in clinical practice, they have many challenges in obtaining an accurate measurement.
There is a tendency for the device not to maintain positioning over the radial artery.
The wrist must be kept at heart level to obtain an accurate reading.
A preliminary analysis of wireless BP monitors showed poor accuracy compared with auscultatory readings.
BP measurements in other settings
Measurements conducted by pharmacists may be an alternative to HBPM for assessing out-of-office BP. However, training/retraining of pharmacists is required.
Kiosks that are commonly used to measure BP often do not have cuffs that fit large arms.
BP measurement in special populations
Children
Oscillometry and auscultation are acceptable for screening BP measurements.
Most normative data are based on auscultatory BP measurements.
If elevated BP is present when measured with an oscillometric device, auscultation should be performed to define BP categories.
BP should be taken in the right arm to align with normative data.
Pregnancy
Because of the hemodynamic and vascular changes that occur during pregnancy, BP measurement devices need to be validated in pregnant women.
A systematic review has reported devices that have been validated in pregnant women.

(*Continued*)

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Table 13. Continued

BP measurement in special populations continued
Obesity
Tronco-conical-shaped BP cuffs may be useful for some obese adults.
A thigh cuff can be used if a person's arm circumference exceeds the largest arm cuff available.
If a thigh cuff does not fit, BP can be measured at the wrist.
Older adults
Sitting and standing BP measurements can be used to identify orthostatic hypotension.
Standing BP should be obtained immediately after rising and 1 and 2 min later.
Orthostatic hypotension has been associated with risk for fractures, syncope, and mortality.
ABPM may be useful in identifying white-coat hypertension, hypotension in the postprandial state, and after awakening in the morning.
BP variability
Short-term BP variability (eg, beat-to-beat, within-visit variability) has low reproducibility and is not associated with risk for CVD events.
Visit-to-visit variability is associated with risk for CVD events.
Calcium channel blockers and thiazide-type diuretics are associated with lower visit-to-visit variability of BP.
Protocol for the validation of BP monitors
There are 4 main validation protocols for BP devices.
These protocols vary in requirements (eg, sample size, range of BP, success criteria).
Many device validation studies do not adhere to these protocols.
Device calibration
Nearly all manufacturers of ABPM devices recommend that the devices be calibrated at regular intervals.
When appropriate, HBPM devices may be brought to a healthcare provider's office to assess calibration.
Biomedical engineering departments can evaluate whether individual devices are taking accurate readings.

ABPM indicates ambulatory blood pressure monitoring; AOBP, automated office blood pressure; BP, blood pressure; CVD, cardiovascular disease; DBP, diastolic blood pressure; HBPM, home blood pressure monitoring; and SBP, systolic blood pressure.

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Patients With Left Ventricular Assist Devices

Many patients with heart failure who are awaiting transplantation or are not candidates for transplantation are supported by continuous-flow left ventricular assist devices. Unlike with older pulsatile-flow left ventricular assist devices, continuous-flow left ventricular assist devices typically do not produce an appreciable pulse because the arterial flow is continuous rather than pulsatile. Therefore, only 1 number is recorded, which is referred to as *mean BP*. BP can be measured in these patients with a Doppler detector over the brachial artery recording the pressure at which the flow in the artery disappears and reappears.[294] Oscillometric methods may be effective in some patients.[295]

BP Variability

BP variability is a term that has been used to describe beat-to-beat, reading-to-reading on ABPM, circadian, within-visit, day-to-day, and between-office-visit changes.[296] In a meta-analysis of 4 studies, SBP variability in the morning, evening, or both was associated with increased all-cause mortality (hazard ratio, 1.17;[95% CI, 1.08–1.27]; hazard ratio, 1.10 [95% CI, 1.01–1.20]; and 1.15 [95% CI, 1.06–1.26] per standard deviation higher morning, evening, or both in combination SBP variability, respectively).[297] Although an association has been present between short-term BP variability on ABPM and cardiovascular outcomes, the value of assessing short-term BP variability remains unclear.[297,298] Short-term BP variability, including beat-to-beat BP variability, is not a very reproducible phenotype. BP variability within office visits has been reported not to be reproducible or associated with cardiovascular outcomes or all-cause mortality.[299,300] Day-to-day variability can be assessed by HBPM.

Over the past decade, a strong association has been reported between long-term BP variability (between office visits) and risk for stroke, coronary heart disease, renal disease, and all-cause mortality independently of mean BP level.[301–304] Although visit-to-visit variability of BP has been associated with CVD outcomes with the use of as few as 3 visits, using ≥7 visits provides a more stable estimate of visit-to-visit variability of BP.[305] Although calcium channel blockers and thiazide-type diuretics have been associated with lower visit-to-visit variability compared with other drug classes, there are no data showing that these drugs reduce CVD events through their effect on lowering visit-to-visit BP variability.[306,307] Low antihypertensive medication adherence has been associated with higher levels of visit-to-visit BP variability.[308,309] However, substantial visit-to-visit BP variability is present among people with high adherence, and visit-to-visit variability of BP is associated with CVD events among individuals not taking antihypertensive medication.[310] The degree to

which the association of visit-to-visit variability of BP and adverse outcomes reflects the presence of arterial stiffness, inflammation, or subclinical CVD is unclear.

Protocols for the Validation of BP Monitors

Protocols for the validation of noninvasive BP monitors were initially established in the 1980s to characterize the accuracy of new devices. Discrepancies between clinical measurements and oscillometric device measurements, including ABPM and HBPM, led to greater scrutiny and the standardization of the protocols in both Europe and the United States. A minority of BP monitor validation studies have correctly adhered to the relevant protocol, and many studies have biased or misrepresented results.[311]

There are 4 main validation protocols for BP devices (Table 12). These protocols use a similar sequential BP measurement procedure and have similar tolerable BP measurement error, yet they vary substantially in sample size requirements, range of BP requirements, characteristics of the participants, which arm should be used, selection of the standard device, selection of the cuff/bladder, and success criteria.[315] The British Hypertension Society validation is the most complex protocol. However, its advantage is that it is thorough and accounts for intradevice variability and consistency in performance after prolonged use. The ESH protocol is on the opposite extreme of complexity, having eliminated some prevalidation steps. It has the smallest sample size requirement and eliminates some of the redundancy seen in the British Hypertension Society protocol. The validation protocol of the Association for the Advancement of Medical Instrumentation is less complex than the British Hypertension Society protocol but requires a similar sample size and participants with a wide range of BP and asks for specific assessment for special populations. Finally, the Quality Seal Protocol from Germany (German Hypertension League) requires the largest sample size and the most well-defined age groups. A new international universal validation protocol (Association for the Advancement of Medical Instrumentation/ESH/International Organization for Standardization) is being developed that may become the new standard for device validation.[24] Separate device validation studies should be performed in special populations, including children, pregnant women, and patients with AF and large arm circumferences (>42 cm).[24]

Device Calibration

Despite a manufacturer's device having satisfied ≥1 of the validation protocols mentioned above, nearly all manufacturers recommend that oscillometric devices, including ABPM, be calibrated at regular intervals (eg, every 1 or 2 years). The frequency of recalibration should follow the manufacturer's recommendation. Some recommend that the device be returned to the manufacturer for recalibration; however, there is often a nontrivial cost for this service. In hospitals and some other settings, there is usually a biomedical engineering department that can evaluate whether each individual device is taking accurate readings. Because of their lower cost and because they are not used in the office setting, there are no standardized protocols for calibrating HBPM devices once they have left the manufacturer. An HBPM device validated in a specific population may not always provide an accurate measure of BP for a specific individual.[34] It is impractical for providers to ask all of their patients to bring their HBPM device to the office and assess the concordance of its readings with those obtained by a healthcare provider with a calibrated device. However, this approach may be appropriate for some individuals in whom it is suspected that home BP readings may be inaccurate despite the use of a validated device.[316]

Summary

Hypertension remains one of the most prevalent CVD risk factors in the United States and worldwide. Accurately measuring BP is essential for the proper diagnosis of hypertension and monitoring the effect of antihypertensive treatment. In addition, BP is a component of CVD risk prediction equations that, in turn, are used to guide the decision to initiate statins, pharmacological antihypertensive medication, and aspirin therapy.[1,317,318] Numerous studies have been published since the 2005 AHA scientific statement on the measurement of BP that inform how to obtain an accurate BP measurement. A list of summary points from each section is provided in Table 13.

In the office setting, the use of oscillometric devices provides an approach to obtain a valid BP measurement that may reduce the human error associated with auscultatory measurements. The use of a validated AOBP device that can be programmed to take and average at least 3 BP readings should be considered the preferred approach for evaluating office BP. To ensure that the patient and staff member are not talking during the measurement, unattended AOBP may be preferred over attended AOBP.

Outside of the office setting, substantial data have been published demonstrating the value of measuring BP with ABPM and HBPM. BP measured by these techniques has a stronger association with CVD risk compared with office-based measurements, with ABPM being the preferred method for out-of-office BP assessment. For the diagnosis of hypertension, the 2017 Hypertension Clinical Practice Guidelines recommend that ABPM be performed, with HBPM used when ABPM is not available. For the management of BP among adults with established hypertension on antihypertensive medication, the 2017 Hypertension Clinical Practice Guidelines recommend that HBPM be done first and ABPM done when confirmatory testing is needed. Finally, we cannot overstate the importance of using only validated devices, routinely calibrating and maintaining BP measurement devices, and having BP measured by healthcare providers who have been properly trained and retrained.

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Disclosures

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*Modest.

†Significant.

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*Modest.

†Significant.

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