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Principles and techniques of blood pressure measurement

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Abstract

Although the mercury sphygmomanometer is widely regarded as the “gold standard” for office blood pressure measurement, the ban on use of mercury devices continues to diminish their role in office and hospital settings. To date, mercury devices have largely been phased out in US hospitals. This has led to the proliferation of non-mercury devices and has changed (probably for ever) the preferable modality of blood pressure measurement in clinic and hospital settings. In this article, the basic techniques of blood pressure measurement and the technical issues associated with measurements in clinical practice are discussed. The devices currently available for hospital and clinic measurements and their important sources of error are presented. Practical advice is given on how the different devices and measurement techniques should be used. Blood pressure measurements in different circumstances and in special populations such as infants, children, pregnant women, elderly persons, and obese subjects are discussed.

Keywords

blood pressure measurement; self-monitoring; ambulatory blood pressure monitoring

Basic techniques of blood pressure measurement

Location of measurement

The standard location for blood pressure measurement is the brachial artery. Monitors that measure pressure at the wrist and fingers have become popular, but it is important to realize that systolic and diastolic pressures vary substantially in different parts of the arterial tree with systolic pressure increasing in more distal arteries, and diastolic pressure decreasing.

The auscultatory method

Although the auscultatory method using mercury sphygmomanometer is regarded as the ‘gold standard’ for office blood pressure measurement, widespread implementation of the ban in use of mercury sphygmomanometers continues to diminish the role of this technique.⁷² The situation is made worse by the fact that existing aneroid manometers,

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which use this technique, are less accurate and often need frequent calibration.⁷² New devices known, as “hybrid” sphygmomanometers, have been developed as replacement for mercury devices. Basically, these devices combine the features of both electronic and auscultatory devices such that the mercury column is replaced by an electronic pressure gauge, similar to oscillometric devices, but the blood pressure is taken in the same manner as a mercury or aneroid device, by an observer using a stethoscope and listening for the Korotkoff sounds.⁷²

The oscillometric technique

This was first demonstrated by Marey in 1876,³⁸ and it was subsequently shown that when the oscillations of pressure in a sphygmomanometer cuff are recorded during gradual deflation, the point of maximal oscillation corresponds to the mean intra-arterial pressure.^{32,39,97} The oscillations begin at approximately systolic pressure and continue below diastolic (Fig. 1), so that systolic and diastolic pressure can only be estimated indirectly according to some empirically derived algorithm. This method is advantageous in that no transducer need be placed over the brachial artery, and it is less susceptible to external noise (but not to low frequency mechanical vibration), and that the cuff can be removed and replaced by the patient during ambulatory monitoring, for example, to take a shower. The main disadvantage is that such recorders do not work well during physical activity when there may be considerable movement artifact. The oscillometric technique has been used successfully in ambulatory blood pressure monitors and home monitors. It should be pointed out that different brands of oscillometric recorders use different algorithms, and there is no generic oscillometric technique. Comparisons of several different commercial models with intra-arterial and Korotkoff sound measurements, however, have shown generally good agreement.^{6,79}

Ultrasound techniques

Devices incorporating this technique use an ultrasound transmitter and receiver placed over the brachial artery under a sphygmomanometer cuff. As the cuff is deflated, the movement of the arterial wall at systolic pressure causes a Doppler phase shift in the reflected ultrasound, and diastolic pressure is recorded as the point at which diminution of arterial motion occurs. Another variation of this method detects the onset of blood flow at systolic pressure, which has been found to be of particular value for measuring pressure in infants and children.¹⁸ In patients with very faint Korotkoff sounds (for example those with muscular atrophy) placing a Doppler probe over the brachial artery may help to detect the systolic pressure, and the same technique can be used for measuring the ankle-brachial index, in which the systolic pressures in the brachial artery and the posterior tibial artery are compared, to obtain an index of peripheral arterial disease.

The finger cuff method of Penaz

This interesting method was first developed by Penaz⁶³ and works on the principle of the “unloaded arterial wall.” Arterial pulsation in a finger is detected by a photo-plethysmograph under a pressure cuff. The output of the plethysmograph is used to drive a servo-loop, which rapidly changes the cuff pressure to keep the output constant, so that the artery is held in a partially opened state. The oscillations of pressure in the cuff are measured and have been found to resemble the intra-arterial pressure wave in most subjects (Fig. 2). This method gives an accurate estimate of the changes of systolic and diastolic pressure when compared to brachial artery pressures;⁶³ the cuff can be kept inflated for up to 2 hours. It is now commercially available as the Finometer and Portapres recorders and has been validated in several studies against intra-arterial pressures.^{61,84} The Portapres enables readings to be taken over 24 hours while the subjects are ambulatory, although it is somewhat cumbersome.²⁷

Technical issues with measurement from the arm

There are important potential sources of error with measurements from the upper arm, which are discussed in the following sections.

Effects of posture—There is no consensus as to whether blood pressure should be routinely measured while seated or supine, although most guidelines recommend sitting.^{67,72} In a survey of 245 subjects of different ages, Netea et al found that systolic pressures were the same in both positions, but there was a systematic age-related discrepancy for diastolic pressure such that at the age of 30 the sitting diastolic was about 10 mm Hg higher than the supine reading, whereas at the age of 70 the difference was only 2 mm Hg.⁴⁹

Body position—Blood pressure measurements are also influenced by the position of the arm.^{45,47,48,94} As shown in Fig. 3, there is a progressive increase in the pressure of about 5 to 6 mm Hg as the arm is moved down from the horizontal to vertical position. These changes are exactly what would be expected from the changes of hydrostatic pressure. It is also important that the patient's back be supported during the measurement; if the patient is sitting bolt upright the diastolic pressure may be up to 6.5 mm Hg higher than if sitting back.¹⁴

Cuff-inflation hypertension—Although in most patients the act of inflating a sphygmomanometer cuff does not itself change the blood pressure, as shown by intra-arterial⁶² and Finapres⁸⁷ recordings, in occasional patients there may be a transient but substantial increase of up to 40 mm Hg coinciding with cuff inflation.⁴² This condition appears to be distinct from white coat hypertension, in which the increase in pressure both precedes the act of inflation and outlasts it. It should also be differentiated from the transient increase of blood pressure that occurs during self-measurement, due to the muscular act of inflating the cuff.

Cuff size—The size of the cuff relative to the diameter of the arm is critical. The most common mistake is to use a cuff that is too small, which will result in an overestimation of the pressure.^{33,40,86} In general, this error can be reduced by using a large adult sized cuff for all except the skinniest arms. The British Hypertension Society (BHS) recommends that if the arm circumference exceeds 33 cm, a large adult cuff should be used (width 12.5 to 13 cm, length 35 cm).⁶⁷ In the United States, the most widely advocated protocol for the selection of the appropriate cuff size is the one recommended by the American Heart Association,⁶⁴ shown in Table 1.

Devices

Validation of monitors

The increasing use of electronic monitors for both self- and ambulatory monitoring has necessitated the development of standard protocols for testing them. The two most widely used have been developed by the BHS⁵² and Association for the Advancement of Medical Instrumentation (AAMI) in the United States.² Both require the taking of three blood pressure readings in 85 subjects (chosen to have a variety of ages and blood pressures) by trained observers and the device being tested. The BHS protocol requires that a device must give at least 50% of readings within 5 mm Hg and 75% within 10 mm Hg with the two methods (grade B), and the AAMI requires that the average difference between the two methods not exceed 5 mm Hg with a standard deviation of less than 8 mm Hg. One of the limitations of the validation procedures is that they analyze the data on a population basis and pay no attention to individual factors. Thus, it is possible that a monitor will pass the validation criteria and still be consistently in error in a substantial number of individuals.²³

Devices for clinic and hospital measurement

Mercury sphygmomanometers—The design of mercury sphygmomanometers has changed little over the past 50 years, except that modern versions are less likely to spill mercury if dropped. As indicated earlier, although the use of mercury sphygmomanometer is widely regarded as the ‘gold standard’ for office blood pressure measurement, widespread implementation of the ban in use of mercury devices continues to diminish their role in office and hospital settings. To date, mercury devices have largely being phased out in US hospitals.⁴³ The reason is not because any more accurate device has been developed but because of concerns about the safety of mercury. Currently the two alternatives for replacement of mercury are aneroid sphygmomanometer and electronic (oscillometric) devices.

Aneroid devices—The ban on mercury sphygmomanometer has placed new interest in alternative methods, of which aneroid devices are the leading contenders. The error rates reported with regards to accuracy of aneroid devices in older hospital surveys range from 1% in one survey,⁸ to 44% in another.⁴⁴ Validation studies conducted a decade ago indicated that they could be accurate.^{4,96} A most recent study, which compared the use of mercury versus aneroid device in the setting of a large clinical trial across over 20 clinical sites, also found it to be accurate.³⁶ This is the best evidence yet attesting to the accuracy of aneroid devices.

Sources of error with the auscultatory method

Some of the major causes of a discrepancy between the conventional clinical measurement of blood pressure and the true blood pressure are listed in Table 2. The measurement of blood pressure typically involves an interaction between the patient and the physician (or whoever is taking the reading), and factors related to both may lead to a tendency to either overestimate or underestimate the true blood pressure or to act as a source of bi-directional error. As shown in Table 2, there may be activities that precede or accompany the measurement that make it unrepresentative of the patient’s “true” pressure. These include exercise and smoking before the measurement as well as talking during it.

The white coat effect and white coat hypertension—One of the main reasons for the growing emphasis on blood pressure readings taken outside the physician’s office or clinic is the white coat effect, which is conceived as the increase of blood pressure that occurs at the time of a clinic visit and dissipates soon thereafter. Recent studies indicate that the mechanisms underlying the white coat effect may include anxiety, a hyperactive alerting response, or a conditioned response^{29,55} In one of these studies, we assessed office blood pressure, ambulatory blood pressure, and anxiety scores on three separate occasions one month apart in 238 patients. We found the largest white coat effect occurred in the physician’s presence, and the noted white coat effect was a conditioned response to the medical environment and the physician’s presence rather than a function of the patients’ trait anxiety level (See Figure 4). The white coat effect is seen to a greater or lesser extent in most if not all hypertensive patients but is much smaller or absent in normotensive individuals. It usually has been defined as the difference between the clinic and daytime ambulatory pressure.⁹¹ A closely linked but discrete entity is white coat hypertension, which refers to a subset of patients who are hypertensive according to their clinic blood pressures but normotensive at other times. Thus, white coat hypertension is a measure of blood pressure levels, whereas the white coat effect is a measure of blood pressure change.

What distinguishes patients with white coat hypertension from those with true or sustained hypertension is not that they have an exaggerated white coat effect but that their blood pressure is within the normal range when they are outside the clinic setting. White coat

hypertension is important clinically because it appears to be a relatively low-risk condition compared to sustained hypertension (defined by an elevated blood pressure in both the clinic and ambulatory settings).¹⁹ It can only be diagnosed reliably by ambulatory monitoring and home self-monitoring as described later. Observer error and observer bias are important sources of error when sphygmomanometers are used. Differences of auditory acuity between observers may lead to consistent errors, and digit preference is very common, with most observers recording a disproportionate number of readings ending in 5 or 0.⁶⁰ An example is shown in Fig. 5 of readings taken by hypertension specialists, who are clearly not immune to this error. The average values of blood pressure recorded by trained individual observers have been found to vary by as much as 5 to 10 mm Hg.¹⁷ The level of pressure that is recorded may also be profoundly influenced by behavioral factors related to the effects of the observer on the subject, the best known of which is the presence of a physician. It has been known for more than 40 years that blood pressures recorded by a physician can be as much as 30 mm Hg higher than pressures taken by the patient at home, using the same technique and in the same posture.³ Physicians also record higher pressures than nurses or technicians.^{37,73} Other factors that influence the pressure that is recorded may include both the race and sex of the observer.^{12,41}

Rate of cuff inflation and deflation—The rate of inflation has no significant effect on the blood pressure,³³ but with very slow rates of deflation (2 mm Hg/s or less) the intensity of the Korotkoff sounds was diminished, resulting in slightly higher diastolic pressures. This effect has been attributed to venous congestion reducing the rate of blood flow during very slow deflation.²⁶ The generally recommended deflation rate is 2 to 3 mm Hg/s. The rate of inflation and deflation is of crucial importance during self-monitoring of blood pressure, because the isometric exercise involved in inflating the cuff produces a transient elevation of pressure of about 10 mm Hg.⁸⁸ Although this lasts for only about 20 seconds, if the cuff is deflated too soon the pressure may not have returned to baseline, and a spuriously high systolic pressure will be recorded.

Auscultatory gap—This can be defined as the loss and reappearance of Korotkoff sounds that occur between systolic and diastolic pressures during cuff deflation in the absence of cardiac arrhythmias. Thus, if its presence is not recognized, it may lead to the registration of spuriously high diastolic or low systolic pressures. It may occur either because of phasic changes of arterial pressure or in patients who have faint Korotkoff sounds (Fig. 6). The auscultatory gap may pose a problem for automatic recorders, which operate by the Korotkoff sound technique, and result in gross errors in the measurement of diastolic pressure.²⁶ Oscillometric devices are less susceptible to this problem.²⁶ Its presence is of clinical significance, because it is associated with an increased prevalence of target organ damage.⁹

Technical sources of error—There are also technical sources of error with the auscultatory method, although these are usually fewer when a mercury column is used than when many of the semiautomatic methods are in use (see later). These error sources include the position of the column, which should be at approximately the level of the heart. The mercury should read zero when no pressure is applied, and it should fall freely when the pressure is reduced (this may not occur if the mercury is not clean or if the pin-hole connecting the mercury column to the atmosphere is blocked). With aneroid meters, it is essential that they be checked against a mercury column both at zero pressure and when pressure is applied to the cuff. Surveys of such devices used in clinical practice frequently have shown them to be inaccurate.⁷

Electronic monitors for self-monitoring of blood pressure

When home monitoring was first used, most studies used aneroid sphygmomanometers.³⁴ More recently however, automatic electronic devices have become more popular. A Gallup poll conducted in 2005 indicated an increase in the number of patients monitoring their blood pressure at home from 38% in 2000 to 55% in 2005. Similarly the proportion of patients owning a monitor increased from 49% in 2000 to 64% in 2005.⁷⁴ The standard type of monitor for home use is now an oscillometric device that records pressure from the brachial artery. These have the advantage of being easy to use, because cuff placement is not as critical as with devices that use a Korotkoff sound microphone, and the oscillometric method has in practice been found to be as reliable as the Korotkoff sound method. The early versions were mostly inaccurate⁸⁵ but the currently available ones are often satisfactory.^{22,53} The advantages of electronic monitors have begun to be appreciated by epidemiologists,¹³ who have always been greatly concerned about the accuracy of clinical blood pressure measurement and have paid much attention to the problems of observer error, digit preference, and the other aforementioned causes of inaccuracy. Cooper et al have made the case that the ease of use of the electronic devices and the relative insensitivity to whom is actually taking the reading can outweigh any inherent inaccuracy compared to the traditional sphygmomanometer method.¹³ Patients should be advised to use only monitors that have been validated for accuracy and reliability according to standard international testing protocols. Unfortunately, only a few of the devices that are currently on the market has been subjected to proper validation tests, such as the AAMI and BHS. An up-to-date list of validated monitors is available on the Dabl Educational Web site (<http://www.dableducational.org>) and the British Hypertension Society Web site (<http://www.bhsoc.org/default.stm>).

Wrist monitors—These monitors have the advantages of being smaller than the arm devices and can be used in obese people, as the wrist diameter is little affected by obesity. A potential problem with wrist monitors is the systematic error introduced by the hydrostatic effect of differences in the position of the wrist relative to the heart,⁴⁵ as shown in Fig. 7. This can be avoided if the wrist is always at heart level when the readings are taken, but there is no way of knowing retrospectively whether this was complied with when a series of readings are reviewed. Wrist monitors have potential but need to be evaluated further.^{16,95}

Finger monitors—Although these monitors are convenient, they have so far been found to be inaccurate and therefore should not be used.⁷⁴

Ambulatory monitors

First developed almost 40 years ago, ambulatory blood pressure monitoring is only now beginning to find acceptance as a clinically useful technique. Recent technologic advances have led to the introduction of monitors that are small and relatively quiet and that can take up to 100 readings of blood pressure over 24 hours while patients go about their normal activities. They are reasonably accurate while the patient is at rest but less so during physical activity. When last systematically surveyed (in 2001), only 24 had been validated according to the AAMI or BHS criteria, of which only 16 satisfied the criteria for accuracy.⁵³ Now many more monitors have been validated and an updated list can be found on the Dabl Educational Web site (<http://www.dableducational.org>). They can in theory provide information about the three main measures of blood pressure: the average level, the diurnal variation, and short-term variability. Recordings in hypertensive patients show that in most patients the average ambulatory pressure is lower than the clinic pressure, and in some cases it may be within the normal range, leading to a diagnosis of white coat hypertension, described later. Given that there is a discrepancy between the clinic and ambulatory pressure, it is reasonable to suppose that the prediction of risk will be different. There are

now more than 30 cross-sectional studies relating the extent of cardiovascular damage to both clinic and ambulatory pressures.⁶⁸ Almost all have shown that the correlation coefficients are higher for ambulatory pressure, although in many instances the differences were small. The superiority of ambulatory pressure in this respect may be attributed at least in part to the greater number of readings and to their more representative nature.

Measurement in different situations

Clinic measurement

The recent interest in alternative methods of measuring blood pressure has served to emphasize some of the potentially correctable deficiencies of the routine clinic measurement of blood pressure. By increasing the number of readings taken per visit and the number of visits as well as by attempting to eliminate sources of error such as digit preference, the reliability of clinic pressure for estimating the true blood pressure and its consequences can be greatly increased. Despite this, it must be remembered that there are a substantial number of subjects with white coat hypertension in whom clinic readings will continue to give unrepresentative values, no matter how many measurements are taken. Surveys of the techniques used by physicians and nurses in actual practice make depressing reading. One performed in a teaching hospital found that not one out of 172 workers followed the American Heart Association guidelines for measuring blood pressure in the clinic setting. Although 68% considered the mercury sphygmomanometer to be the most accurate, only 38% chose to use it when given a choice, and 60% were judged to be taking blood pressure inaccurately.⁹³

Self-measurement

The potential advantages of having patients take their own blood pressure are twofold: the distortion produced by the white coat effect is eliminated, and multiple readings can be taken over prolonged periods. Self-measurement of blood pressure at home has been shown to be useful in predicting target organ damage, cardiovascular events and mortality.⁷⁴ Five prospective studies have compared the prediction of morbid events with the use of both conventional office and home blood pressure. Three were based on population samples, and 2 recruited hypertensive patients. Four studies found that home BP was the stronger predictor of risk. The fifth found that both BP measures predicted risk.^{5,20,57,59,80} The most recent population-based study of comparative prognosis of self-monitoring versus office BP in predicting cardiovascular events and total mortality among 2081 adults, was the Finn-Home Study.⁵¹ Although home BP and office BP were strongly associated with cardiovascular events in separate Cox proportional hazard models, when both modalities were included in the model, home BP (Hazard Ratio [HR], 1.22/1.15; 95% CI, 1.09 to 1.37/1.05 to 1.26) was remained a strong predictor of cardiovascular events per 10/5 mm Hg increase in blood pressure, while office BP was not predictive (HR, 1.01/1.06; 95% CI, 0.92 to 1.12/0.97 to 1.16). Similarly, home systolic blood pressure was the only predictor of total mortality (HR, 1.11; 95% CI, 1.01/1.23)). This study is the second population-based study to conclusively confirm the superior prognostic value of home BP versus office Bp on total mortality. The concern about the potential for observer error than with physician readings can often be mitigated by use of automated devices with memory chips. These allow the physician to recall the blood pressure readings taken by their patients. Whereas exclusive reliance on self-monitored readings is not recommended, they can provide a useful adjunct to clinic readings, both for the initial evaluation of newly diagnosed patients and for monitoring their response to treatment.

Ambulatory blood pressure monitoring

There are six prospective studies to date showing that ambulatory blood pressure is a better predictor of risk than clinic pressure and more are on the way. The first, published by Perloff et al.,^{65,66} used noninvasive monitoring performed during the day only and reported that those whose ambulatory pressure was low in relation to their clinic pressure were at lower risk of morbidity. The second, by Verdecchia et al.,⁹⁰ followed a group of 1187 normotensive and hypertensive individuals for 3 years; hypertensive subjects were classified as having white coat or sustained hypertension. The morbid event rate was 0.49 per 100 patient-years in white coat hypertensive patients (similar to the rate of 0.47 in the normotensive subjects), whereas it was 1.79 in hypertensive dippers, who constituted the majority, and 4.99 in nondippers. The third study is the pilot results of a population study in Ohasama, Japan,⁵⁸ which reported that ambulatory pressure was a better predictor of morbidity than screening pressure; no attempt was made to classify individuals as having white coat hypertension. The fourth⁷⁷ is a study of patients with refractory hypertension, defined as a diastolic pressure above 100 mm Hg while on three or more antihypertensive medications. Patients were classified in three groups according to their daytime ambulatory pressure; those in the lowest tertile (below 88 mm Hg) had a significantly lower rate of morbidity over the next 4 years, despite similar clinic pressures. A fifth study, from Northwick Park Hospital in London,³⁰ followed 479 patients for nearly 10 years, all of whom were initially evaluated with intra-arterial ambulatory blood pressure monitoring using the intra-arterial technique. Patients were classified as having white coat or sustained hypertension, and it was found that a diagnosis of white coat hypertension was associated with one-third the risk of cardiovascular morbidity as sustained hypertension. The sixth study in this series is Syst-Eur, a large placebo-controlled study of the effects on cardiovascular morbidity of treating systolic hypertension of the elderly with a calcium channel blocker. A substudy of 808 patients used ambulatory blood pressure monitoring, and found that ambulatory blood pressure was a much more potent predictor of risk than office blood pressure.⁸³ The findings from these older studies were confirmed by more recent data in other prospective studies. Thus, although these prognostic studies differed widely in their design, ranging from a population study to one of refractory hypertensive subjects, the results all point in the same direction, namely that ambulatory pressure gives a better prediction of prognosis after controlling for clinic pressure, the corollary of which is that patients with white coat hypertension have a more benign prognosis than those with sustained hypertension.

How should different blood pressure measurement techniques be used?

Which measures of blood pressure are clinically important?

There are potentially three major measures of blood pressure that could contribute to the adverse effects of hypertension. The first is the average or “true” level, the second is the diurnal variation, and the third the short-term variability.

Average clinic blood pressure—Presently, epidemiologic and clinical data are available only for the average level of blood pressure. In clinical practice, a patient’s blood pressure is typically characterized by a single value of the systolic and diastolic pressures, to denote the average level. Such readings are normally taken in a clinic setting, but there is extensive evidence that in hypertensive patients, clinic pressures are consistently higher than the average 24-hour pressures recorded with ambulatory monitors.⁷⁰ This overestimation by clinic readings of the true pressure at high levels of pressure and underestimation at low levels has been referred to as the regression dilution bias and means that the slope of the line relating blood pressure and cardiovascular morbidity should be steeper for the true blood pressure than for the clinic pressure.⁷¹

Diurnal variation in blood pressure—There is a pronounced diurnal rhythm of blood pressure, with a decrease of 10 to 20 mm Hg during sleep and a prompt increase on waking and rising in the morning. The highest blood pressures are usually seen between 6 AM and noon, which is also the time at which the prevalence of many cardiovascular morbid events tends to be highest.⁴⁶ The pattern of blood pressure during the day is to a large extent dependent on the pattern of activity, with pressures tending to be higher during the hours of work and lower while at home.¹¹ In hypertensive patients, the diurnal blood pressure profile is reset at a higher level of pressure, with preservation of the normal pattern in the majority. The short-term blood pressure variability is increased when expressed in absolute terms (mm Hg), but the percentage changes are no different. Thus, hypertension can be regarded as a disturbance of the set point or tonic level of blood pressure with normal short-term regulation. Antihypertensive treatment reverses these changes, again by resetting the set point toward normal, with little effect on short-term variability. The normal diurnal rhythm of blood pressure is disturbed in some hypertensive individuals, with loss of the normal nocturnal fall of pressure. This has been observed in a variety of conditions, including malignant hypertension, chronic renal failure, several types of secondary hypertension, pre-eclampsia, and conditions associated with autonomic neuropathy.⁷¹ There is ample evidence linking elevated nighttime blood pressure to increased cardiovascular morbidity and mortality compared to daytime blood pressure. In the Ohasamma population-based study, a 5% reduction in night time BP resulted in up to 20% higher risk of cardiovascular mortality.⁵⁶ Similarly, a 9 mm Hg increase in nighttime diastolic BP was associated a 25% increased risk of congestive heart failure among elderly Swedish men.²⁸ In the Syst-Eur trial,⁸³ a large placebo-controlled study of the effects on cardiovascular morbidity of treating systolic hypertension of the elderly with a calcium channel blocker, a substudy of 808 patients used ambulatory blood pressure monitoring. Staessen et al found that nighttime blood pressure was a better predictor of cardiovascular morbidity and mortality than daytime blood pressure.⁸³ Although these findings are not sufficiently well established to be applied to routine clinical practice, the clinical significance of nocturnal hypertension and nondipping status cannot be ignored for long, given the potential beneficial effect of the treatment of nocturnal hypertension on cardiovascular disease risk reduction in hypertensive patients.¹⁰

Blood pressure variability—Information on the clinical significance of blood pressure variability has accumulated over the past decade with recent data suggesting that increased ambulatory blood pressure variability is associated with the development of early carotid arteriosclerosis,⁷⁸ and a high rate of cardiovascular morbidity.³¹ More recently, in a prospective ambulatory blood pressure study of initially untreated sample of 2649 hypertensive patients, Vedecchia and colleagues compared the independent prognostic value of daytime and nighttime blood pressure variability for cardiovascular events. They found elevated nighttime systolic blood pressure to be an independent predictor of cardiac events.⁸⁹ Similarly, among elderly patients in the Syst-Eur trial, increased nighttime systolic blood pressure variability on admission to the Syst-Eur trial was an independent risk factor for stroke during the trial among those in the placebo arm of the trial. (refs Systolic blood pressure variability as a risk factor for stroke and cardiovascular mortality in the elderly hypertensive population.⁷⁵

The combined use of clinic, home, and ambulatory monitoring

The measurement of clinic blood pressure, either by use of automated devices or conventional sphygmomanometry, will continue to be the principal method of clinical evaluation. A cardinal rule is that the closer the blood pressure is to the threshold level at which treatment will be started, the more readings should be taken over more visits, before treatment decision is made. In patients who have persistently elevated clinic pressure and

evidence of blood pressure–related target organ damage, it is usually unnecessary to supplement the clinic readings with other types of measurement before reaching a therapeutic decision. When an elevated blood pressure is the only detectable abnormality, however, the possibility that the clinic pressure may overestimate the true pressure should be considered. This can be done either by self-monitoring or by ambulatory monitoring. A schema for the use of the different procedures for measuring blood pressure when evaluating a newly diagnosed hypertensive patient is shown in Fig. 8. If self-monitoring is chosen and reveals pressures comparable to the clinic value, treatment may be appropriate; but if the home readings are much lower than the clinic readings, it does not rule out the possibility that the blood pressure may be elevated at work. This is the advantage of ambulatory monitoring, which gives the best estimate of the full range of blood pressure experienced during everyday life.

Measurement of blood pressure in special populations and circumstances

Infants and children

The Korotkoff sound technique is recommended as the standard for children older than the age of 1 year; however, it may give systematic errors in infants, in whom the sounds are difficult to hear, and thus the true systolic pressure may be underestimated.¹⁸ In infants the best indirect measurement technique is an ultrasonic flow detector.⁷⁶ A particular problem associated with blood pressure measurement in children of different ages is knowing which sized cuff to choose. The BHS recommends choosing from three cuff sizes—4×13 cm, 8×18 cm, and 12×35 cm (adult cuff)—and putting on the widest cuff that will fit the arm.¹⁵ The American Heart Association,⁶⁴ and the National High Blood Pressure Education Program (NHBPEP),¹ have recommended that the cuff size be standardized to the circumference of the arm.

Pregnant women

In normal pregnancy there is a fall of blood pressure, together with an increase of cardiac output and a large decrease of peripheral resistance. As a result of this hyperkinetic state, Korotkoff-like sounds occasionally may be heard over the brachial artery without any pressure being applied to the cuff. These sounds are most probably due to turbulent flow in the artery. Consequently, the use of phase 4 has frequently been recommended for registering diastolic pressure in pregnant women, which may be 12 mm Hg higher than phase 5.⁹² The NHBPEP Working Group report recommends recording both phases 4 and 5 throughout pregnancy.³⁵ In one study of 85 pregnant women, however, phase 5 never approached zero, and phase 4 could be identified in only half, leading the authors to recommend phase 5.⁸¹

Elderly patients

In some older people there is an increase of systolic pressure without a corresponding increase of diastolic pressure (systolic hypertension), which has been attributed to a diminished distensibility of the arteries with increasing age. In extreme cases this may result in a diminished compressibility of the artery by the sphygmomanometer cuff, so that falsely high readings may be recorded, often referred to as pseudohypertension of the elderly.⁸² These patients represent the exception rather than the rule, however, because studies of healthy elderly subjects have not shown any greater discrepancy between direct and indirect measurements of pressure than in younger subjects.^{21,54}

Obese patients

It is well known that the accurate estimation of blood pressure using the auscultatory method requires an appropriate match between cuff size and arm diameter. In obese subjects the

regular adult cuff (12×23 cm) may seriously overestimate blood pressure.⁵⁰ The effect of arm circumference on the cuff method of measuring blood pressure was studied systematically by King.³²

Exercise

During dynamic exercise the auscultatory method may underestimate systolic pressure by up to 15 mm Hg, whereas during recovery it may be overestimated by 30 mm Hg.^{24,25} Errors in diastolic pressure are unlikely to be as large, except during the recovery period, when falsely low readings may be recorded.²⁴ This is the reason why the American Heart Association recommends taking the fourth phase of the Korotkoff sound after exercise.⁶⁴

Summary

Although the use of mercury sphygmomanometer is regarded as the ‘gold standard’ for office blood pressure measurement, widespread ban in use of mercury devices has diminished their role in hospital settings. Alternative methods such as automated electronic devices have gained increased popularity. The preferred location of measurement is the upper arm, but errors may occur because of changes in the position of the arm. Other technical sources of error include inappropriate cuff size and too rapid deflation of the cuff. Clinic readings may be unrepresentative of the patient’s true blood pressure because of the white coat effect, which is defined as the difference between the clinic readings and the average daytime blood pressure. Patients with elevated clinic pressure and normal daytime pressure are said to have white coat hypertension, which is often explained by state anxiety or conditioned response. There are three commonly used methods for measuring blood pressure for clinical purposes: clinic readings, self-monitoring by the patient at home, and 24-hour ambulatory readings. Self-monitoring is generally carried out using electronic devices that work on the oscillometric technique. Although standard validation protocols exist, many devices on the market have not been tested for accuracy. Such devices can record blood pressure from the upper arm, wrist, or finger, but the arm is preferred. Twenty-four-hour ambulatory monitoring is the best predictor of cardiovascular risk in the individual patient and is the only technique that can describe the diurnal rhythm of blood pressure accurately. Ambulatory monitoring is mainly used for diagnosing hypertension, whereas self-monitoring is used for following the response to treatment. Different techniques of blood pressure measurement may be preferred in certain situations. In infants the ultrasound technique is best, whereas in pregnancy and after exercise the diastolic pressure may be hard to measure using the conventional auscultatory method. In obese subjects it is important to use a cuff of the correct size.

Acknowledgments

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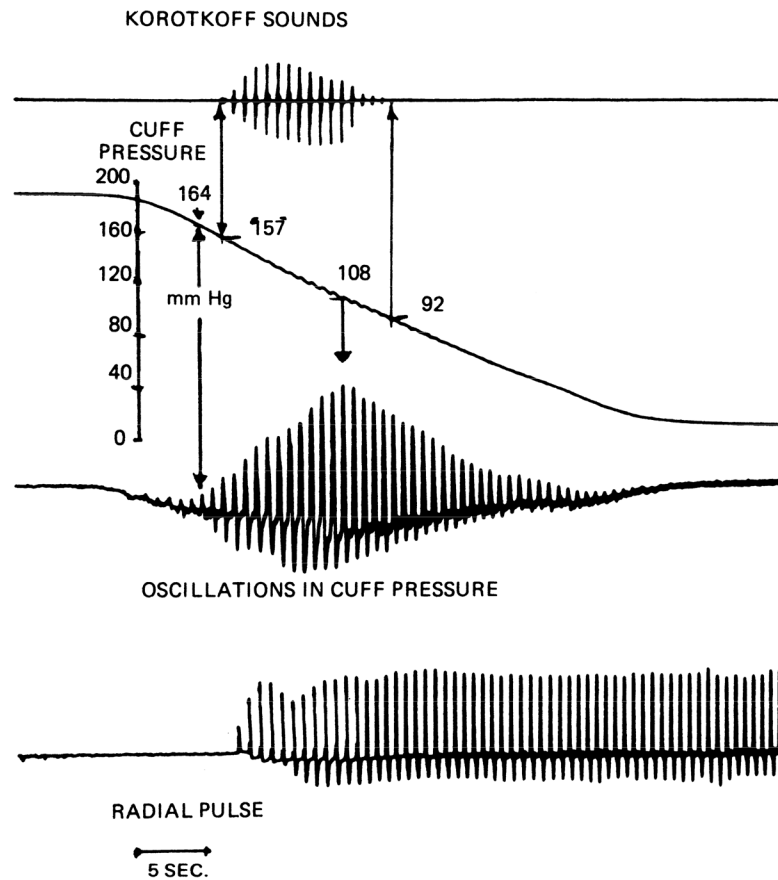


Fig. 1. Changes occurring distal to a sphygmomanometer cuff during deflation. *Upper trace:* Korotkoff sounds. *Second trace:* cuff pressure. *Third trace:* oscillations in cuff pressure. The maximal oscillation occurs at a pressure of 108 mm Hg, the mean arterial pressure. *Bottom trace:* radial pulse. *From* Pickering TG. Blood pressure variability and ambulatory monitoring. *Curr Opin Nephrol Hypertens* 1993a;2:380; with permission

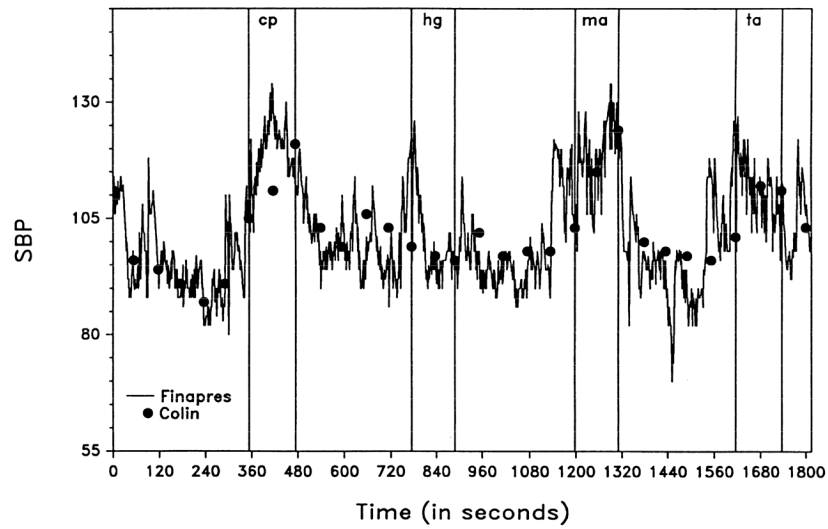


Fig. 2. Recording of systolic pressure during laboratory stress testing, made simultaneously with a continuous beat-to-beat monitor (Finapres) and an intermittent oscillometric device (Colin). Cp = cold pressor test; hg = handgrip; ma = mental arithmetic; ta = talking.

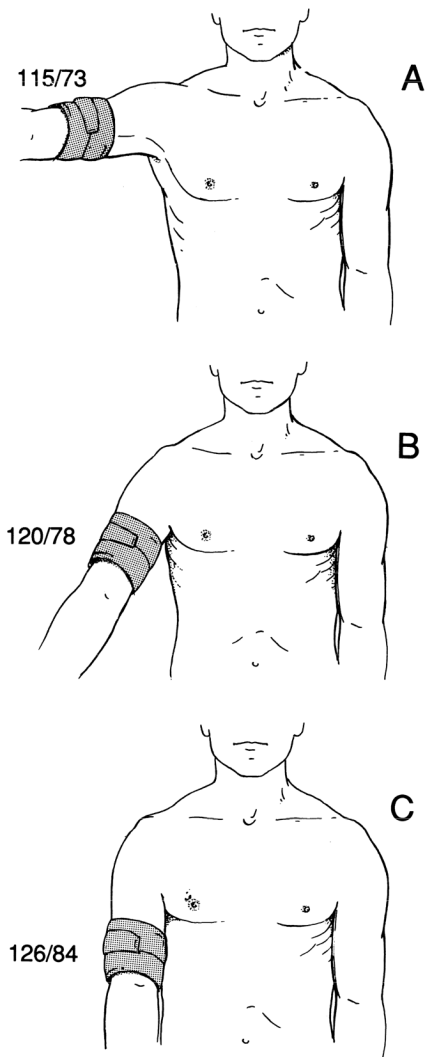


Fig. 3. The effects of varying arm position on blood pressure recorded from the brachial artery. From Pickering TG. Blood pressure variability and ambulatory monitoring. *Curr Opin Nephrol Hypertens* 1993a;2:380; with permission.

Self-rated anxiety score before (pre) and after (post) BP (BP) measurement in different conditions.

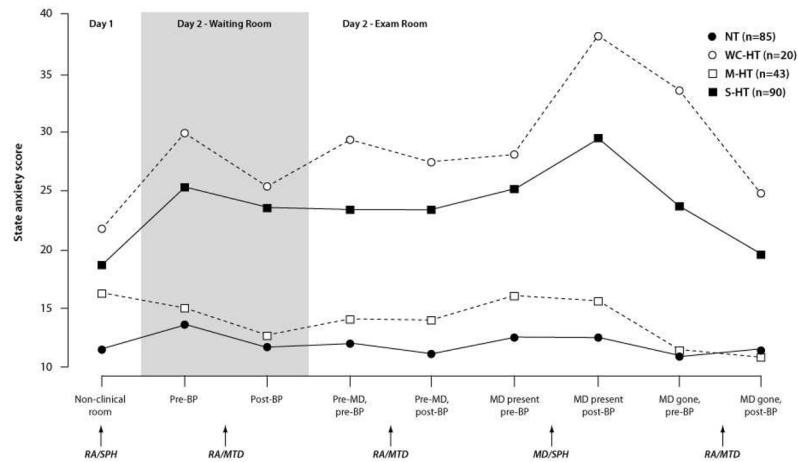


Fig. 4. Self-rated anxiety score before (pre) and after (post) BP (BP) measurement in different conditions. On day 1, the research assistant (RA) measured BP outside the medical environment using a mercury sphygmomanometer (SPH). On day 2, the RA measured BP in the absence of a physician (MD) by manually triggering a device for ambulatory BP measurement (MTD) first in the waiting room and next in the examination before and after the MD measured BP using SPH. Anxiety scores were obtained in normotensive subjects (NT) and in patients with white coat hypertension (WC-HT), masked hypertension (M-HT), and sustained hypertension (S-HT). *Reproduced with permission from Ogedegbe G, Pickering TG, Clemow L, et al. The misdiagnosis of hypertension: the role of patient anxiety. Arch Intern Med. Dec 8 2008; 168(22): 2459–2465.*

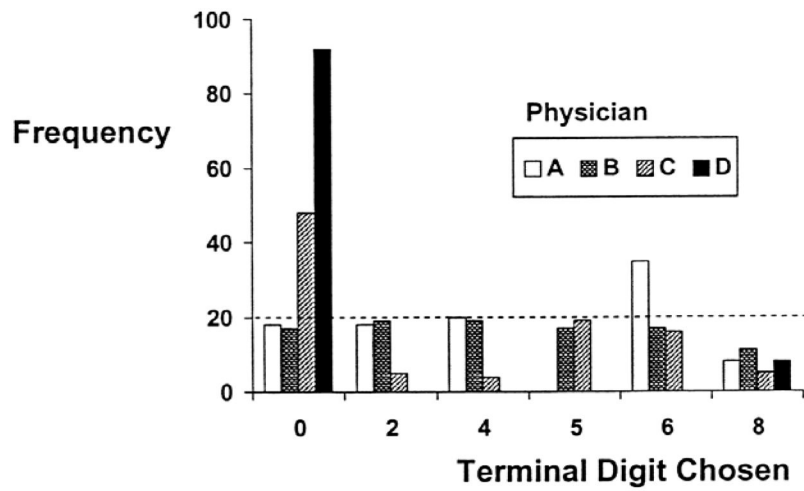


Fig. 5. The percentage of terminal digits chosen by four physicians in a Hypertension Clinic during routine blood pressure measurement. Note the marked preference for zeroes in physicians C and D.

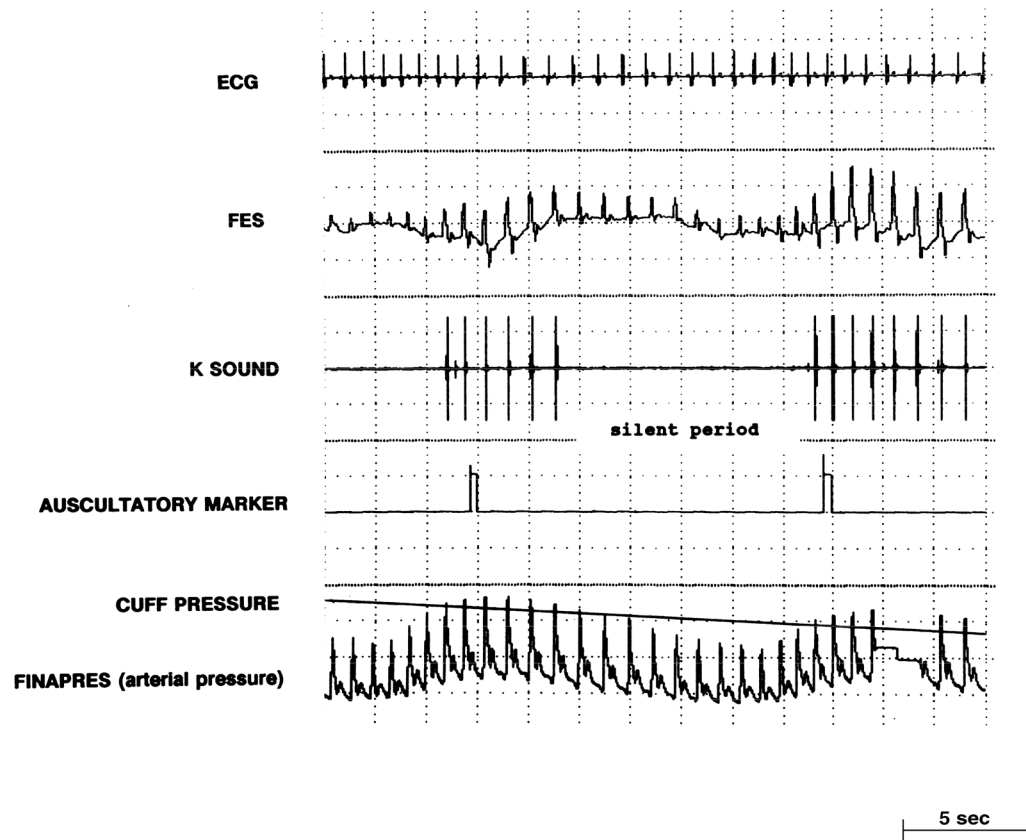


Fig. 6. The phenomenon of the auscultatory gap during cuff deflation. Upper trace: ECG. Second trace: low frequency recording of sounds under the sphygmomanometer cuff. Third trace: Korotkoff sounds. Fourth trace: auscultatory marker pressed when systolic and diastolic sounds were heard. Fifth trace: cuff pressure. Sixth trace: Finapres recording of arterial pressure; note oscillations of pressure corresponding to silent period of K sounds. From Pickering TG. Blood pressure variability and ambulatory monitoring. *Curr Opin Nephrol Hypertens* 1993a;2:380; with permission.

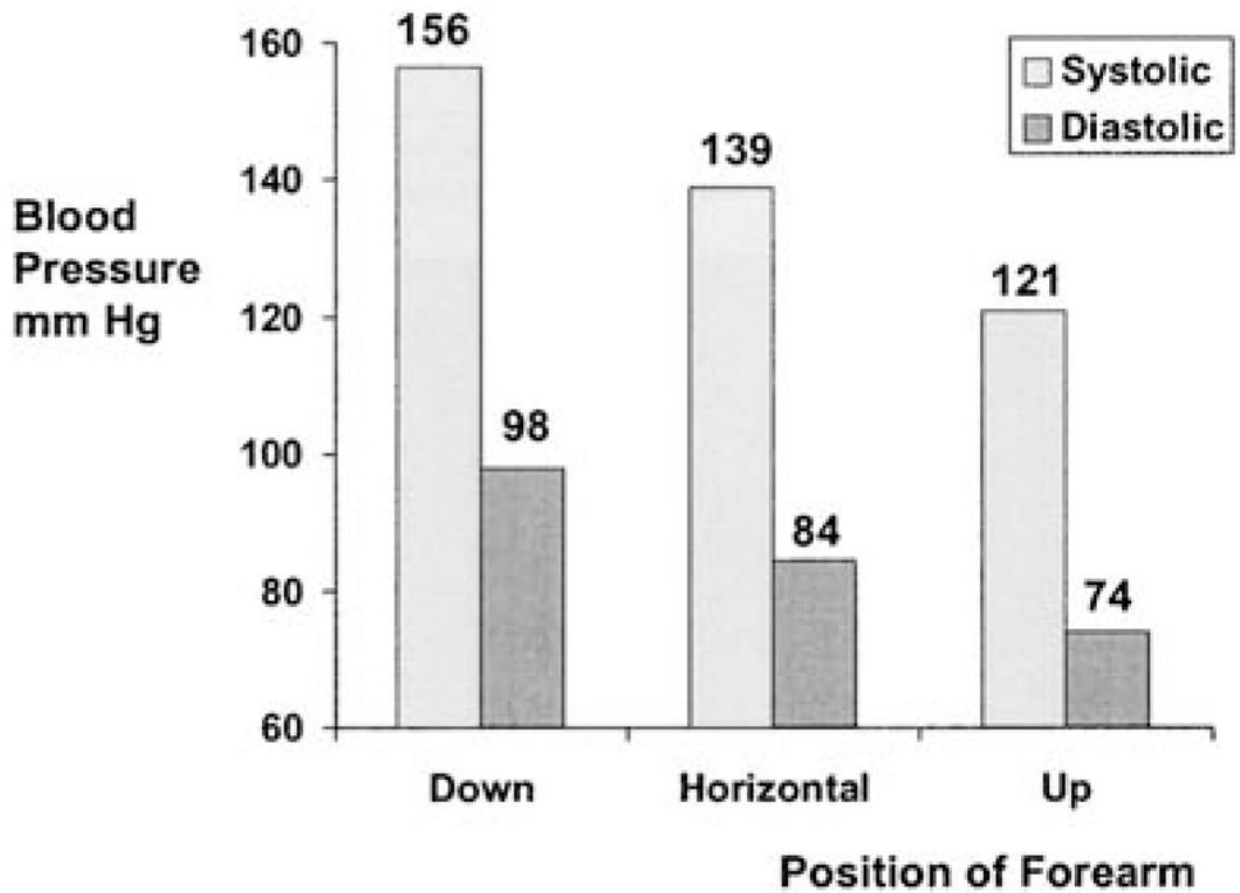


Fig. 7. The effects of changes in the position of the forearm on the blood pressure recorded by a wrist monitor. Ten readings were taken in each of three positions: vertically down, horizontal, and vertically up. The average values are shown at the top of each bar.

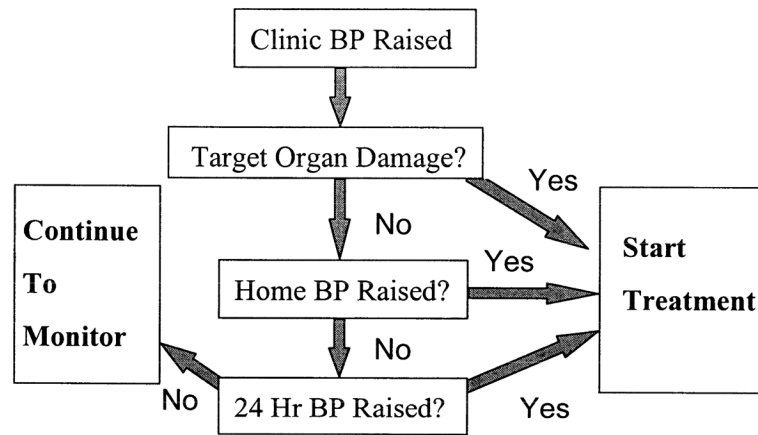


Fig. 8. Schema for combining different measures of blood pressure in the evaluation of patients with suspected hypertension.

Table 1

Cuff sizes recommended by the American Heart Association

Cuff	Arm circumference (cm)	Bladder width (cm)	Bladder length (cm)
Newborn	<6	3	6
Infant	6–15	5	15
Child	16–21	8	21
Small adult	22–26	10	24
Adult	27–34	13	30
Large adult	35–44	16	38
Adult thigh	45–52	20	42

Table 2
 Patient- and physician-related factors that lead to a discrepancy between clinic and true BP

	Clinic BP overestimates true BP	Bidirectional error	Clinic BP underestimates true BP
Physician	Inadequate cuff size	Digit preference	
Patient	White coat effect/anxiety Talking Recent ingestion of pressor substances	Spontaneous BP variability	Smoker Recent exercise