Expert Review  Measurement of Blood Pressure

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Abstract: Accurate measurement of blood pressure is an important skill for medical students and doctors. This article presents a comprehensive, concise and evidence-based method for the measurement of blood pressure, consistent with The Principles of Clinical Examination [1]. We describe the abnormalities of blood pressure which may be detected on examination and, based on a review of the literature, the precision and accuracy of these signs is discussed.

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Introduction

It is important that blood pressure is measured accurately. Acutely, useful information can be gained about a patient's cardiovascular status and haemodynamic stability, helping clinicians to identify inappropriately low BP and medical emergencies, like clinical shock [2]. Chronically, population screening for hypertension enables early detection and initiation of treatment, prior to the onset of end-organ damage [3]. Despite its importance, the measurement of BP by auscultation is notoriously imprecise and inaccurate, with up to 97% of clinicians deviating from best practice [4].

Inaccuracy of blood pressure measurement may have far-reaching clinical consequences. For example, consistent underestimation of diastolic BP by 5 mmHg could lead to almost two-thirds of individuals with hypertension being misdiagnosed as normotensive, and being denied potentially life-saving treatment [5]. Conversely, overestimation of diastolic pressure by 5 mmHg could more than double the number of individuals erroneously diagnosed as hypertensive, leaving them at risk of over-treatment [6]. Factors responsible for this imprecision include the inherent variability of blood pressure, the so-called "white coat effect", the accuracy of the devices being used and suboptimal measurement techniques [6].

The techniques described in this paper are widely regarded as best practice, minimise errors and inter-examiner variability, and underpin many current international guidelines [2, 3, 7, 8]. These are also the techniques against which measurement devices, such as automated or ambulatory machines, are evaluated for accuracy by national bodies like the British Society for Hypertension [9]. These techniques have not, however, been validated against alternative methods, such as invasive BP monitoring using a radial arterial catheter as it is contentious that these intra-arterial measuring techniques are gold standard as some might suggest, particularly in elderly patients with rigid blood vessels [2].

The Sphygmomanometer

BP is most commonly measured in the clinic using an inflatable cuff to occlude the brachial artery (although other arteries can be used), and then auscultating medial to the biceps tendon in the elbow crease with a stethoscope [6] (see figures 1 and 2).

A sphygmomanometer comprises the cuff, an inflation-deflation system and a pressure reading device. The cuff is an inelastic cloth enclosing an inflatable rubber bladder which is wrapped around the upper arm and fastened (usually with Velcro™). A handheld pump is then used to inflate the cuff to a pressure above...
brachial arterial pressure at which point blood flow is obliterated. While gradually deflating the cuff, the examiner simultaneously auscultates the brachial artery and inspects the falling pressure readings using the manometer.

Figure 1  The anatomy of the brachial artery
(A) Deltoid (B) Pectoralis major (C) Biceps brachii (D) Triceps brachii (E) Brachial artery (F) Biceps tendon (G) Brachioradialis (H) Bicipital aponeurosis (I) Pronator teres

Korotkoff Sounds
At some point during deflation, the brachial arterial pressure exceeds the deflating cuff pressure, causing resumption of blood flow through the artery. Initially, this flow is pulsatile, causing repetitive, tapping sounds heard using a stethoscope, so-called Korotkoff sounds named after the Russian physician who first described the auscultatory method in 1905 [13]. As blood flow strengthens and becomes more consistent, the sounds ebb and finally disappear completely. From their first appearance to their final disappearance, the Korotkoff sounds go through five phases (see Table 1). Systolic BP corresponds to the pressure at which sounds first appear. The pressure at which they permanently disappear (Phase V) is taken to correspond to diastolic pressure, although historically this has been much debated [2].

In some patients, sounds may disappear completely for a brief period between Phases II and III. This is known as the auscultatory gap [17].

There are several exceptions to the rule that Korotkoff Phase I equates to systolic pressure and Phase V to diastolic pressure [2]. In children under thirteen years, pregnant women and patients with peripheral vasodilation or high cardiac output, sounds may remain audible for a protracted period after they first become muffled (Phase IV). Therefore, for these categories of patients, diastolic pressure is taken as the pressure at the onset of muffling (Phase IV).

Korotkoff sounds are not reliably audible in infants under one year old, or in many children under five years of age. Therefore, in these groups, alternative measurement techniques such as oscillometry may be required (see box 2) [8].

Literature Search
The PubMed database was searched using the MeSH terms “blood pressure”, “hypotension”, “hypertension”, “blood pressure determination” and the non-MeSH terms "postural hypotension" and “orthostatic hypotension”. These terms were entered into the clinical queries filter under “diagnosis”, “narrow, specific search” and also “clinical prediction rules”, “narrow, specific search”. The results retrieved were then combined with the MeSH terms “physical examination”, “diagnostic tests, routine” and “monitoring, physiologic”. A similar search of the EMBASE database was performed. Limiting the results from both databases to papers concerning humans, written in English and published in the last ten years yielded a total number of 373 papers. Of these, 31 abstracts were judged relevant and retrieved in full, and further papers from their reference lists were selected.

In addition, Medline and internet search engines were used to identify guidelines for blood pressure measurement issued by some of the key international bodies responsible for investigating cardiovascular disease such as the American Heart Association, the British Hypertension Society, the European Society of Hypertension and the United Kingdom's National Institute for Clinical Excellence. Finally, the following textbooks of clinical examination were searched:

Macleod’s Clinical Examination [10]
Browse’s Introduction to the Symptoms and Signs of Surgical Disease [11]
Clinical Examination: A Systematic Guide to Physical Diagnosis [12]
Phase | Definition
--- | ---
I | The first appearance of Korotkoff sounds. Roughly coincides with the reappearance of a palpable Pulse. (To ensure the first sound heard is not extraneous at least two consecutive beats should be heard and should increase in intensity as the cuff pressure falls [13]).
II | A brief period may follow during which the sounds become softer and longer
III | The sounds become clear and louder
IV | The sounds become muffled and less distinct
V | The sounds disappear completely

### Table 1 Phases of BP measurement

#### Preparation

**The Examiner**

Start by washing your hands, introducing yourself to the patient, checking the patient's identity, explaining the procedure and obtaining informed consent. You should also establish whether or not the patient is in any pain.

For the procedure itself, you should be comfortably positioned in a way that will allow you to inflate and deflate the cuff, to see the cuff pressure reading, and to distinguish the Korotkoff sounds from background noise. A pen and paper should be ready to note down the findings immediately [17].

**The Patient**

The patient should ideally be comfortably seated in a quiet, warm environment, with the midpoint of the upper arm at the level of the right atrium – approximately the fourth intercostal space (see figure 3) [18, 19]. Positioning the arm above or below this level leads to underestimation or overestimation respectively of both systolic and diastolic pressures due to the effects of hydrostatic pressure [20]. The BP changes 2mm Hg for every inch above or below heart level [21].

The back and arm should be supported comfortably against a chair and a table top since, if unsupported, isometric contraction of muscles can artificially elevate BP readings by as much as 10% [6, 20]. Furthermore, BP tends to rise during any activity, so measurement should be preceded by several minutes of inactivity. Talking may also elevate pressure, so the patient should remain silent during measurement [21]. Ideally the patient should be wearing loose fitting clothing that can be rolled up the arm so that it does not get in the way of the cuff or constrict the upper arm during the measurement. Clothing which constricts the arm or sits beneath the cuff has been shown to artificially elevate the recorded BP [22].

If the patient is supine on the bed and cannot tolerate sitting up, the arm should be elevated by a pillow. This is because the right atrium is at the level halfway between the bed and the sternum [23]. Even adjusting for this, the systolic pressures have been reported on average 8mm Hg higher than when the subject is in an upright position [24].

#### Selection of Cuff

In order to select an appropriately sized cuff, you should inspect or measure (using a tape) the circumference of the bare upper arm at a point midway between the shoulder and the elbow. The bladder inside the cuff should encircle 80% of this point in the arm in adults (100% in children aged under 13 years) [21]. Mismatching of the bladder and arm size distorts results. An inappropriately small cuff overestimates BP, leading to so-called “cuff hypertension”, and too large a cuff underestimates BP [21, 25]. It has been shown that BP errors are larger when the cuff is too small than when it is too large.

#### Placement of The Cuff

Ensure the centre of the bladder rests over the brachial artery: marked helpfully in many cuffs by an arrow labelled ‘artery’. The lower edge of the cuff should be positioned 2-3 cm above the classical brachial artery pulsation in the antecubital fossa (see figure 2) [15].

#### Rough Estimation of Systolic Pressure Using Palpation

With the cuff securely fastened, palpate the brachial pulse with one hand while with the other you inflate the cuff to approximately 30 mmHg above the point at which the brachial pulsation disappears. Slowly deflate the cuff until the pulse reappears, at which point a rough estimation of systolic blood pressure has been obtained. Palpatory estimation of BP prior to auscultatory measurement is important to avoid underestimation of blood pressure in those patients with an auscultatory gap (as described above).

#### Auscultatory Measurement of Systolic and Diastolic Pressures

Place the bell (ideally, although the diaphragm is easier to hold in place) of your stethoscope over the brachial artery pulsation and hold it firmly in place...
while rapidly inflating the cuff to 20-30 mmHg above the estimated systolic pressure estimate you have just obtained. Partially unscrew the valve and deflate the cuff at no more than 2mmHg/sec whilst listening carefully for the appearance of Korotkoff sounds. Deflating the cuff too rapidly can underestimate BP [27].

Note the pressures, rounded upwards to the nearest 2 mmHg, at which repetitive sounds first appear (phase I) and when they disappear (phase V). Once the last sounds are heard, deflate the cuff slowly for a further 10mmHg to ensure no further sounds are audible, and then rapidly deflate the cuff. Once fully deflated and removed, record the BP on paper as soon possible in order to minimise errors. If the patient is anxious, restless or distressed, a note of this should be made since these factors may contribute to overestimation of BP.

Repeating measurements like this is important but rarely done in practice due to the extra time it takes.

Figure 2  The correct positioning of the sphygmomanometer cuff and the stethoscope on the patient's arm

Ideally, after allowing the patient to rest for at least 30 seconds, obtain a second reading in the same arm, and average the two readings. Since many studies have demonstrated significant differences in the pressures recorded in a subject's left and right arms, the procedure should then be repeated in the other arm, and the higher of the two arms readings taken as the future reference arm [8]. If systolic differences of greater than 20 mmHg are present on three consecutive occasions, the patient should be referred to a cardiovascular specialist for assessment [8].
### Table 2  Common causes of BP measurement inaccuracies

<table>
<thead>
<tr>
<th><strong>Problem</strong></th>
<th><strong>Resulting inaccuracy</strong></th>
<th><strong>Avoidance technique</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Patient factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm below heart level</td>
<td>BP too high</td>
<td>Position mid-point of upper arm at heart level</td>
</tr>
<tr>
<td>Arm above heart level</td>
<td>BP too low</td>
<td>Position mid-point of upper arm at heart level</td>
</tr>
<tr>
<td>Back unsupported</td>
<td>BP too high</td>
<td>Support back</td>
</tr>
<tr>
<td>Arm unsupported</td>
<td>BP too high</td>
<td>Support arm</td>
</tr>
<tr>
<td>Subject talking, moving, or unrested</td>
<td>BP too high</td>
<td>Ensure subject is still, silent and rested</td>
</tr>
<tr>
<td>Subject stressed, anxious, in pain or frightened</td>
<td>BP too high</td>
<td>Comfort patient as much as possible; ambulatory BP measurement</td>
</tr>
<tr>
<td><strong>Examiner factors</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cuff too loose</td>
<td>BP too high</td>
<td>Apply cuff more tightly</td>
</tr>
<tr>
<td>Cuff applied over clothing</td>
<td>BP inaccurate</td>
<td>Apply cuff over bare arm</td>
</tr>
<tr>
<td>Deflation rate too fast</td>
<td>Systolic pressure too low</td>
<td>Deflate at 2 mmHg/sec max.</td>
</tr>
<tr>
<td>Poor memory</td>
<td>Inaccurate reading</td>
<td>Write down reading immediately</td>
</tr>
</tbody>
</table>

### Other BP Measuring Locations

**Legs:** Patients who have undergone axillary node dissection usually secondary to breast cancer are advised not to have BP taken in the affected arm due to a purported increased risk of developing lymphoedema. The evidence is severely lacking, however, with no level I or level II evidence to support this claim. In patients with bilateral node dissection, the BP is measured in the legs. The procedure for measuring BP in the legs is the same as in the arms except the appropriate sized cuff (bladder 80% of the circumference of the thigh) should be placed around the mid-thigh and the popliteal artery should be auscultated (behind the knee in the popliteal fossa). The systolic pressure is, moreover, normally 10-20% higher than brachial arterial pressure.

**Forearm:** Other BP monitoring locations such as the wrists are occasionally used: for example in morbidly obese patients that cannot be cuffed normally due to a short upper arm length and extremely large arm circumferences. The cuff is placed around the forearm and the clinician listens for sounds over the radial artery.

It is important to note that systolic and diastolic BPs vary significantly between different parts of the arterial tree. As BP is monitored more distally, the systolic pressures tend to increase whilst the diastolic pressure decrease.

### Groups in which accurate blood pressure measurement is challenging

1. **Individuals affected by white coat hypertension**

   The sympathetic stimulation that accompanies anxiety can raise BP by as much as 30 mmHg. In most people, reassurance from a doctor and familiarisation with the measurement technique reduces or eliminates completely any anxiety-related elevation of their BP. However, certain normotensive patients still become hypertensive, even though their pressures subsequently return to normal. This “white coat effect” is estimated to raise BP by more than 20/10 mmHg in up to 40% of patients. In order to achieve accurate readings in these patients, ambulatory BP measurement or home measurement may be necessary (see box 2 below).

2. **The elderly**

   Blood vessels tend to calcify with age. Sclerotic, stiffened arteries in the elderly with decreased vessel wall compliance can lead to the overestimation of systolic BP and an erroneous diagnosis of hypertension. In addition to this pseudohypertension, the elderly often suffer from orthostatic hypotension, defined as a drop in either systolic pressure of more than 20 mmHg, or diastolic pressure of more than 10 mmHg, within 3 minutes of standing. Sudden drops in BP are responsible for a significant proportion of falls in the elderly and are hence a cause of substantial mortality and morbidity in this age group. Appropriate technique for establishing the presence of a postural drop is therefore imperative. A widely-used, though not infallible protocol involves...
measuring the patient’s BP after they have rested supine for at least 5 minutes. The patient is then asked to stand motionless for 3 minutes while the examiner repeatedly measures BP with the arm supported at heart level [34].

3. Children
Paediatric cuffs are available in various sizes and should be selected so that the bladder completely encircles the child’s limb [1]. Because Korotkoff sounds are frequently inaudible in children under 5 years, alternative techniques such as oscillometry may be necessary (see box 2 below) [1].

4. Individuals with arrhythmias, particularly atrial fibrillation
Irregular cardiac rhythms frequently lead to beat-to-beat variation in BP since stroke volume (and hence BP) during each cardiac cycle are dependent on the length of the preceding pulse interval. Therefore, in a highly variable rhythm such as atrial fibrillation, there is not a single BP measurement, but in reality a range of BPs in which the true value lies. Any individual recorded figure is at best a rough estimate and should be recorded as such. The American Heart Association recommends minimising error by taking multiple readings in patients with arrhythmias and recording their average value [1].

Alternative techniques for blood pressure measurement
1. Ambulatory blood pressure monitoring (ABPM)

ABPM involves individuals repeatedly recording their BP away from the clinical environment, while going about their everyday activities for a period of (usually) 24 hours, using a portable, automatic device (see oscillometry below). ABPM is particularly useful in white coat hypertension, in patients with fluctuating BP readings, and in an attempt to correlate low or high BPs with self-reported symptoms. Only devices whose accuracy has been rigorously validated using protocols drafted by national bodies such as the British Society for Hypertension should be used [35].

2. Home self-monitoring
Self-measurement of BP in the home setting using an electronic device has a high specificity for detecting white coat hypertension [38]. However, the accuracy of home devices is not always well validated, nor are there currently large-scale data demonstrating the usefulness of home monitoring [36].

3. Oscillometry
Most ambulatory and home devices are electronic machines which measure blood pressure oscillometrically, meaning that in place of a stethoscope auscultating Korotkoff sounds, an electronic pressure sensor is used to detect fluctuations in blood flow. When arterial blood flow is partially restricted by the cuff, the cuff pressure will vary with the cyclical expansion and contraction of the pulsating artery, that is, it will oscillate. A computer algorithm converts the degree of oscillation into figures for systolic and diastolic pressures.

The accuracy of the readings provided by these machines is contentious, even in patients with ‘normal’, stable BP [36]. This method is particularly inaccurate in other groups, for example, individuals with pre-eclampsia, an irregular pulse or in whom BP fluctuates. Furthermore, there is not adequate data to validate their use in older people, whose arteries do not vibrate in the same way as younger patients. Many commercially available devices have not been correctly calibrated according to international protocols. Their use is, therefore, inadvisable.

Conflicts of interest
None declared.
References


