Blood pressure measurement in pregnancy and in hypertensive disorders of pregnancy: devices, techniques and challenges

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Abstract

Measurement of blood pressure is essential for clinical management of patients. To obtain an accurate blood pressure reading, the use of a validated device and an appropriate technique are required. This is of particular importance in pregnancy where the physiological changes affect vessel wall compliance. Moreover, currently it is difficult to predict in early pregnancy (prior to 20 weeks of gestation) which women would develop hypertension or pre-eclampsia. For this reason, blood pressure devices require validation in pregnancy and in hypertensive disorders of pregnancy to ensure that accurate readings are obtained and utilised for clinical decisions, otherwise the safety of the mother or the foetus/neonate or both may be compromised. The authors provide a narrative review on devices and techniques for blood pressure measurement in pregnancy and hypertensive disorders of pregnancy as well as the associated challenges.

Keywords: blood pressure devices, importance of blood pressure measurement, myocardial performance, pre-eclampsia, rate pressure product, vascular changes in pregnancy

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Each year, over 70 000 maternal deaths and over 500 000 foetal and neonatal deaths occur as a result of pre-eclampsia (PE). In 2015, a global maternal mortality ratio of 216 deaths per 100 000 live births was reported, and hypertensive disorders of pregnancy (HDP), mainly the category PE, accounted for 14% of these deaths with most of the mortalities occurring in low- and middle-income countries (LMIC). In the 2014–2016 triennium in South Africa, HDP accounted for an in-hospital maternal mortality ratio of 24.01 per 100 000 live births. Sixty-six per cent of these maternal deaths were associated with an avoidable factor, including failure by some healthcare practitioners to manage severe hypertension as an emergency. Maternal deaths due to HDP in other countries are also associated with suboptimal management in different aspects of patient care, such as antihypertensive therapy, stabilisation prior to delivery, timing of delivery and quality of care.

One of the ways to reduce the morbidity and mortality rate from HDP is to ensure accurate measurement of blood pressure. To a large extent, the steps involved in the measurement of blood pressure in pregnancy are the same as in the non-pregnant state. Unfortunately, a number of reports indicate that healthcare practitioners do not always use the recommended techniques to measure blood pressure. Additionally, due to the concern of mercury toxicity, automated blood pressure-measuring devices have been introduced to replace mercury sphygmomanometers. However, automated blood pressure devices are prone to errors in pregnancy and especially in HDP due to haemodynamic changes that alter vascular wall compliance. To ensure accuracy, automated blood pressure devices used for the measurement of blood pressure in pregnancy have to pass a validation protocol or a baseline check recommendation. The immediate and long-term complications of poorly managed HDP make this topic important. These complications include posterior reversible leukoencephalopathy syndrome, stroke, retinal disorders, cerebral white matter lesions and increased risk of mortality in early adulthood, to mention but a few. Additionally, the category of HDP called PE is a risk factor for the development of cardiovascular and metabolic disorders at a later stage in life. Furthermore, offspring of pre-eclamptic mothers are at risk of major health issues such as impaired motor development, increased childhood blood pressure and stroke in adulthood.

The aim of this narrative review, therefore, is to elaborate on devices and techniques for the measurement of blood pressure in pregnancy and HDP, and in particular PE. This review also discusses and offers solutions to the challenges associated with conventional blood pressure measurement in pregnancy. The index report will be valuable to healthcare professionals and researchers who provide medical care to pregnant women.

Classification of hypertensive disorders of pregnancy

Hypertension in pregnancy is defined as systolic blood pressure ≥ 140 mmHg and or diastolic blood pressure ≥ 90 mmHg.
and these levels must be attained or exceeded during a repeat measurement.\textsuperscript{1} Notably, the blood pressure threshold that is used to define hypertension is dependent on the situation of measurement: clinic \(\geq 140/90 \) mmHg; home \(\geq 135/85 \) mmHg; ambulatory blood pressure prior to 22 weeks\’ gestational age \(\geq 126/76 \) mmHg (24-hour average), \(\geq 132/79 \) mmHg (awake average) and \(\geq 114/66 \) mmHg (sleep average).\textsuperscript{1}

In 2018, the International Society for the Study of Hypertension in Pregnancy (ISSHP) classified HDP as PE, transient gestational hypertension, gestational hypertension, white-coat hypertension, masked hypertension, chronic hypertension and chronic hypertension with superimposed PE.\textsuperscript{1} PE is the development of new-onset hypertension in pregnancy at or beyond the gestational age of 20 weeks, with the presence of significant proteinuria and/or maternal organ dysfunction or placental insufficiency.\textsuperscript{1} Gestational hypertension is a new-onset hypertension after 20 weeks of gestational age. Transient gestational hypertension is transient occurrence of hypertension at any stage of pregnancy with spontaneous resolution without treatment. Chronic hypertension is that which exists prior to 20 weeks\’ gestational age. White-coat hypertension is the occurrence of hypertension only in a medical practitioner’s office/clinic with normalisation of the blood pressure \(< 135/85 \) mmHg outside the health facility.\textsuperscript{1,12} Masked hypertension is the occurrence of hypertension in other settings other than the medical practitioner’s office/clinic setting.

Gestational hypertension \((15–25\%)\textsuperscript{19}\) and chronic hypertension \((25\%)\textsuperscript{19}\) will progress to PE. Additionally, 20\% of patients with transient gestational hypertension will develop either gestational hypertension or PE.\textsuperscript{19} Data on white-coat hypertension and masked hypertension in pregnancy are limited, but these disorders are not innocuous. For instance, 40 and 8\% of white-coat hypertension will progress to gestational hypertension and PE, respectively.\textsuperscript{25}

**Haemodynamic and vascular changes that affect accuracy of blood pressure measurement**

Haemodynamic and cardiovascular changes occur in pregnancy, resulting in hyperdynamic circulation,\textsuperscript{26} with aberrations in this physiology contributing to clinical features of HDP. Of note, blood pressure is the product of cardiac output and systemic vascular resistance, and blood pressure monitors function by assessing the blood flow and or changes in the vessel wall.\textsuperscript{26}

In pregnancy, stroke volume and heart rate are increased and these elevate the cardiac output, and in tandem, the peripheral vascular resistance is decreased.\textsuperscript{11} Pregnancy also increases the production of relaxin, which remodels or softens collagen by degradation via upregulation of both matrix metalloproteinases and tissue inhibitors of metalloproteinases.\textsuperscript{7} In the non-pregnant state, relaxin has also been found to reverse fibrosis, possibly by preventing collagen synthesis through downregulation of fibroblast activation, proliferation and secretion.\textsuperscript{8} These changes occur in the vasculature, alter the stiffness/compliance and capacitance of the vessel wall, and these mechanisms are acceptable to investigators.\textsuperscript{34–45} In fact, it has been reported that the arterial compliance is increased by 30\% in the first trimester and remains elevated thereafter during pregnancy.\textsuperscript{11}

In PE, mediators such as soluble fms-like tyrosine kinase-1 (sFlt-1) injure the endothelium and alter vascular reactivity.\textsuperscript{44–45} Therefore, vascular compliance in non-pregnancy, healthy pregnancy\textsuperscript{46} and HDP\textsuperscript{47} differs, and blood pressure devices require validation in these conditions. The changes in vascular compliance support the use of augmentation index and pulse-wave velocities (both of which are measures of arterial stiffness) as indices of cardiovascular risk in early pregnancy\textsuperscript{48} and after a pre-eclamptic pregnancy.\textsuperscript{49}

**Importance of accurate blood pressure measurement in pregnancy**

Accurate measurement of blood pressure assesses the overall health status and is crucial in the antenatal, intrapartum and postpartum periods and impacts on both maternal and perinatal outcomes. In the antenatal period (but not limited to this period), measurement of blood pressure is useful for: (1) screening for PE: the US Preventive Services Task Force recommends blood pressure measurement during each prenatal visit as the method of screening for HDP;\textsuperscript{44} (2) prediction of adverse pregnancy outcomes such as foetal growth restriction\textsuperscript{50} and/or PE;\textsuperscript{41,52} (3) diagnosis of cardiovascular diseases: apart from hypertension, measurement of blood pressure on both right and left arms during the first clinic visit may reveal a significant pressure difference that will assist in the diagnosis of coarctation of the aorta; and (4) helps to trigger the commencement and adjustment of the dose of antihypertensive medication.

The following is the usefulness of intrapartum blood pressure measurement. (1) During labour, blood flows from the uteroplacental vasculature\textsuperscript{26} to the rest of the circulation. This increases the stroke volume, cardiac output \((11\%)\textsuperscript{13}\) and blood pressure. Therefore, care must be taken to monitor the blood pressure to safeguard against complications such as stroke, eclampsia and cardiac failure. (2) The presence of hypertension during endotracheal intubation is a risk factor for stroke during the procedure. (3) Blood pressure measurement will also assist in the diagnosis of hypotension and calculation of shock index (pulse rate divided by systolic blood pressure), which may assist in determining the need for blood transfusion in a bleeding patient and predicting adverse pregnancy outcomes. It has been shown that in a study involving 958 women with obstetric haemorrhage in a low-resource setting that a shock index \(> 0.9\) indicates the need for referral while \(> 1.4\) signals the need for urgent intervention, including blood transfusion in a tertiary centre.\textsuperscript{9}

It is important to note that rate pressure product, which is a product of systolic blood pressure \((\text{mmHg})\) and pulse rate, is different from shock index. Rate pressure product indicates cardiac oxygen consumption and may be useful in individuals who are anaesthetised or exercising.\textsuperscript{51,52} Future studies are required to possibly expand its role in pregnancy and HDP.

In the postpartum period, measurement of blood pressure is useful for the diagnosis of hypotension, which may signal postpartum haemorrhage, or in the diagnosis of severe hypertension, which may result in catastrophic complications such as eclampsia and stroke. It is important to note that the majority of cases of postpartum eclampsia occur in the first 48\textsuperscript{th} to 72\textsuperscript{th} hours following childbirth. Therefore the patient, particularly those with a diagnosis of HDP, must have frequent blood pressure measurements in this period. Understandably, a lack of hospital beds may lead to early hospital discharge,
but in such circumstances out-patient or home blood pressure monitoring is mandatory.

**Blood pressure-measuring devices**

Blood pressure devices may be broadly categorised into invasive (intra-arterial line) and non-invasive. The non-invasive types are auscultatory and non-auscultatory. Mercury, aneroid and non-mercury liquid crystal sphygmomanometers are examples of auscultatory types of devices. The non-auscultatory types include automated, ambulatory and Doppler ultrasound devices.

**Invasive blood pressure monitoring**

The invasive (intra-arterial line) blood pressure monitoring involves placement of a cannula into an artery (usually radial) with the distal end of the cannula attached to tubing, which is then connected to a pressure transducer. Infusion of heparinised saline through the tubing and cannula prevents a blood clot in the set-up. Both numerical measurements and graphical recording of the blood pressure are displayed on a monitor in real time, and this helps with dynamic management of patients. With each heartbeat, the blood pressure waveform rises during systole and drops during diastole, and the average mean arterial blood pressure over one cardiac cycle is indicated numerically.

In clinical practice, the intra-arterial device is used in the management of critically ill patients, many of whom have labile arterial blood pressures. Such clinically ill pregnant women include those with septic shock, severe obstetric haemorrhage, eclampsia and other forms of acute organ failure requiring resuscitation. Arterial blood gas samples may also be obtained from the arterial line.

Additionally, the validation of a blood pressure device may be undertaken using an intra-arterial device as a reference standard. In fact, the validation of neonatal blood pressure devices may only be performed using an intra-arterial device as a reference standard.

Non-invasive blood pressure monitoring, on the other hand, is used in all categories of patients, particularly in non-critically ill patients.

**Non-invasive auscultatory blood pressure-measuring device**

Measurement of blood pressure with an auscultatory device involves using a functional stethoscope to listen to the sound produced when blood flows through a partially occluded brachial artery, as well as the subsequent changes in the sound prior to non-occlusion of the vessel. The origin of the sound is not clearly understood but is thought to emanate from one or both of the following: turbulence to blood flow and stretching of the arterial wall.

In this method of blood pressure measurement (mercury/ aneroid sphygmomanometry), the cuff is inflated on the arm to occlude the brachial artery and is subsequently deflated. The radial artery in the wrist is palpated during the cuff inflation, and the pressure at which the arterial pulsation ceases is noted. Subsequently, the cuff should be inflated further to increase the pressure by an additional 20–30 mmHg above the point where the radial pulse is no longer palpable. A stethoscope is placed on the antecubital fossa, distal to the cuff, to auscultate the Korotkoff sound during deflation. The first sound (Korotkoff phase I) is heard when the pressure in the cuff begins to allow blood flow through the artery.

The cuff pressure at which Korotkoff phase I sound is heard represents the systolic blood pressure. Direct palpation of the arterial pulse while the cuff pressure is inflating imprecisely indicates the systolic blood pressure. The diastolic blood pressure is denoted by the disappearance of the sound (Korotkoff phase V). Should the sound not disappear, the pressure at muffling of the sound (Korotkoff phase IV) denotes the diastolic blood pressure.

The traditional auscultatory device has a mercury column and its use is no longer popular in many clinical settings due to concerns of mercury toxicity. Irrespective, the European Commission Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) recommends that mercury sphygmomanometers may be used for the validation of other blood pressure-measuring devices.

An aneroid device is a good replacement for the mercury sphygmomanometers. The aneroid device, however, tends to lose calibration easily, especially due to mechanical trauma. Therefore, a mobile aneroid device mounted on a wall or tripod stand is preferable. Re-calibration of an aneroid device is required at least once every two years. For research purposes, a new aneroid sphygmomanometer with a valid calibration status is recommended for use.

Of note, all blood pressure-measuring devices including mercury sphygmomanometers require periodic assessment and recalibration, although the robustness of the equipment will influence the frequency of this quality check. Evidence-based details of auscultatory and automated blood pressure measurement techniques are described in Table 1.

**Automated blood pressure-measuring device**

The automated or oscillatory blood pressure monitor functions on the principle that flow of blood through an artery partially constricted with a cuff causes the arterial wall to vibrate. Such vibration does not occur if there is no arterial wall constriction. To explain, the inflation of the cuff of the oscillatory blood pressure monitor causes partial or complete constriction of the artery. A cuff pressure above the systolic blood pressure causes complete constriction of the arterial wall. A reduction in the cuff pressure just below the systolic blood pressure causes partial constriction of the arterial wall. With each cardiac contraction, a pulsatile blood flow occurs and causes vibrations in the partially constricted arterial wall. The air in the cuff conducts and transfers the vibration to the transducer in the monitor. The arterial wall vibrations generate pressure pulses of approximately 3 mmHg in the cuff. It is the transducer that then generates an electric signal using the transmitted vibrations.

The oscillatory monitor may be classified as inflationary or deflational. An inflationary device detects the oscillation in the arterial wall when the cuff is inflating. It prevents the need for the pneumatic cuff to be over-inflated substantially above the systolic blood pressure. In the deflational type, the cuff inflates to a pre-determined pressure above the systolic blood pressure before deflating at a rate of approximately 4 mmHg per second to detect the arterial wall oscillations. As soon as the pressure...
Amplitude are used to establish the systolic and diastolic blood pressure, while the changes in the oscillatory pressure pulses are subjected to a functional stethoscope.

Ideally, the woman should rest for > 5 minutes seated quietly with her shoulders supported comfortably on a backrest of a chair/seat. Left lateral decubitus position may be used if patient is unable to sit.

Expose the arm and determine its circumference to select appropriate cuff. The cuff should be 1.5 times the mid-upper arm circumference and the bladder encircles 80% of arm. BP should be measured on both arms during the first visit. The arm where the BP is highest should be used for the subsequent measurement, especially if the systolic BP difference is > 20 mmHg. The left arm should be used for measurement if BP of both arms cannot be assessed initially. Cuff size of 15 cm should be used if the arm circumference is > 33 cm.

Wrap the bare arm with the cuff and ensure that the bladder is centred over the brachial artery. The patient's arm should be outstretched and the mid-width of the cuff should be at the same horizontal plane with the right atrium (i.e. at the level of mid-length of the sternum). The patient should not cross her legs. The cuff should be placed to expose the cubital fossa and aid auscultation of the brachial artery.

8. Palpate the radial artery, keep doing so and inflate the cuff to a pressure where the radial artery pulsation disappears. Then deflate the cuff completely. This step prevents missing an auscultatory gap.

9. Inflate the cuff up to 20–30 mmHg above the pressure level at which the radial artery pulsation disappeared. Then deflate the pressure at a rate of 2 mmHg/sec while auscultating the brachial artery at the cubital fossa using a functional stethoscope.

According to the pressure at which the 1st sound (Korotkoff sound) is heard represents the systolic BP and the disappearance of the sound (Korotkoff V) denotes the diastolic BP. If the Korotkoff sound does not disappear, the pressure at which the sound muffles (Korotkoff IV) will denote diastolic BP. Auscultation of the artery is not required when using an automated BP device.

Further steps for both auscultatory and automated methods

10. For auscultatory device, repeat step 9 above twice at intervals of 1–2 minutes apart to obtain 2nd and 3rd BP readings. Discard the 1st reading as this is a range-finding measurement. Determine the average of the 2nd and 3rd readings to obtain the BP of the patient. For automated device, the average of a total of two measurements (1st and 2nd) should be regarded as the BP value.

The National Institute of Clinical Excellence recommends: if the 1st BP is > 140/90 mmHg, take 2nd measurement. If the difference between the 1st and 2nd readings is substantial, take 3rd measurement. The lowest reading should be regarded as the BP.

11. Re-check the BP in the next 15 minutes if severe hypertension (BP > 160/110 mmHg) is diagnosed. Repeating BP measurement assists to exclude the effect of anxiety.

12. Explain the BP reading to patient/guardian and institute further care.

If the equipment for BP measurements are available, the first step of the procedure is patient preparation. Discuss the reason and the steps involved in BP measurement with the patient and/or her guardian. May not be applicable in some emergency situations.

Inflate the cuff up to 20–30 mmHg above the pressure level at which the radial artery pulsation disappeared. Then deflate the pressure at a rate of 2 mmHg/sec while auscultating the brachial artery at the cubital fossa using a functional stethoscope.

Importantly, the pressure at maximum oscillation corresponds to the mean arterial pressure, while the changes in the oscillatory amplitude are used to establish the systolic and diastolic blood pressures. Automated devices therefore measure the systolic and diastolic blood pressures by processing the oscillometric pulses generated from the arterial wall.

The cuff may be applied at different sites of the body including arm, wrist and finger. Clinicians and investigators should note that the blood pressure will change the more distal and inferior to the heart the cuff is applied. Importantly, automated blood pressure devices may be used within and outside the health facility such as at home, and examples are listed in Table 2.

Oscillogonometry: this functions by reconstructing the brachial blood pressure waveform from a finger blood pressure waveform. Finapres® (FINger Arterial PRESure) and Finometer® are examples of finger devices that function as continuous non-invasive blood pressure monitors. Portapres is a non-invasive ambulatory finger blood pressure device. Continuous non-invasive blood pressure monitoring is finding use in pregnancy, such as in monitoring fluctuating blood pressure during caesarean delivery under subarachnoid blockade.

Semi-automated device: the Microlife 3ASI-2 is a deflationary semi-automated cheap and accurate device that has been validated and approved for use in pregnancy (Table 2), especially in LMIC. This device was validated in a research project called CRADLE (Community blood pressure monitoring in Rural Africa and Asia: Detection of underLying pre-Eclampsia). During its use, the cuff needs to be applied on the arm and inflated manually above the systolic blood pressure. The device is semi-automated partly because it uses batteries (two AAA batteries) and the blood pressure displays automatically during manual deflation of the cuff but requires no auscultation.

Another example of a semi-automated arm-type blood pressure device is UA-704 (A&D Company, Ltd, Tokyo, Japan).

Home blood pressure monitor: this has a role in the management of hypertension as long as the device has been checked for accuracy. It has great value in the diagnosis of white-coat and masked hypertension when the use of an ambulatory blood pressure monitor is not practicable. The

Table 1. Techniques of auscultatory and automated blood pressure (BP) measurement

<table>
<thead>
<tr>
<th>Initial steps for both auscultatory and automated methods</th>
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<tbody>
<tr>
<td>1. If the equipment for BP measurements are available, the first step of the procedure is patient preparation. Discuss the reason and the steps involved in BP measurement with the patient and/or her guardian. May not be applicable in some emergency situations.</td>
</tr>
<tr>
<td>2. Obtain permission to measure BP.</td>
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<tr>
<td>3. Examine the radial or brachial pulse and determine the rate and regularity. Automated devices may be inaccurate if the pulse is irregular.</td>
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<tr>
<td>4. Assemble the equipment for BP measurement, if not yet done. A validated device with a valid calibration status is required. Auscultatory method requires a functional stethoscope.</td>
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<td>5. Ideally, the woman should rest for &gt; 5 minutes seated quietly with her shoulders supported comfortably on a backrest of a chair/seat. Left lateral decubitus position may be used if patient is unable to sit.</td>
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Table 2. Examples of automated blood pressure devices validated in pregnancy and pre-eclampsia

<table>
<thead>
<tr>
<th>Home devices</th>
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<tbody>
<tr>
<td>• Omron MIT.</td>
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<td>• Omron M7 (HEM-780-E).</td>
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<table>
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<tr>
<th>Clinic devices</th>
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<tbody>
<tr>
<td>• Omron MIT Elite (HEM-7300-WE).</td>
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<tr>
<td>• Microlife 3ASI-2 (semi-automated device).</td>
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<tr>
<td>• Microlife WatchBP Home (BP3MX1-1).</td>
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<tr>
<td>• Omron Evolv (HEM-7600T-E). Validated in pregnancy.</td>
</tr>
<tr>
<td>• Omron M3 Comfort (HEM-7134-E). Validated in pregnancy.</td>
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<tr>
<td>• A&amp;D UM-101.</td>
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<tr>
<td>• Omron HEM907.</td>
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<tr>
<td>• Dinamap ProCare 400.</td>
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<td>• Nissequ DS-400.</td>
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<table>
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<tr>
<th>Ambulatory devices</th>
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<tbody>
<tr>
<td>• BP lab.</td>
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<tr>
<td>• Welch Allyn QuietTrack.</td>
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</table>
reading may alert the user to seek medical attention for further evaluation and adjustment of the dose of antihypertensive therapy.9 It also has the potential to reduce the number of patient visits to health facilities.10

A comprehensive assessment of blood pressure with a home device is obtained by measuring the blood pressure on two separate occasions in the morning hours and twice at different times in the evening for at least three days10 but preferably five to seven days.7 Table 2 contains a list of automated home devices validated in pregnancy.

Ambulatory blood pressure monitor

The ambulatory blood pressure monitor is a self-inflating device programmed to frequently measure blood pressure at set time intervals over 24 hours while the patient may be outside the health facility. Given the multiple blood pressure measurements, blood pressure variability is easily demonstrated.

The minimum amount of information to be included in a clinical report of ambulatory blood pressure monitoring measurements has been proposed.106 Such information is aimed at improving the interpretation of an ambulatory blood pressure monitoring report irrespective of the make of the device and the software used for analysis. This minimum information includes: (1) the quality of the ambulatory blood pressure monitor recording; (2) a list of each and every blood pressure recorded; (3) a graphical representation of each reading; (4) a graphical representation of the average systolic and diastolic blood pressure per hour; (5) the 24-hour mean blood pressure, pulse pressure and heart rate; (6) the mean values of the blood pressure, pulse pressure and heart rate in daytime and night-time; (7) maximum and minimum blood pressure, pulse pressure and heart rate obtained during the entire period of measurement; (8) standard deviation of the blood pressure, pulse pressure and heart rate for the 24-hour, daytime and night-time periods; (9) daytime minus night-time values of blood pressure, pulse pressure and heart rate, and (10) percentage blood pressure load in 24 hours, daytime and night-time.102

A major role of the ambulatory blood pressure monitor in the clinical management of pregnant women is in the detection of blood pressure variability, aiding the diagnosis of white-coat hypertension, chronic hypertension,103 and masked hypertension. For instance, in a pregnant woman with office hypertension, ambulatory blood pressure monitoring will assist in distinguishing white-coat hypertension from chronic hypertension.103

Nonetheless, it is important to emphasise that up to 15% of research participants using ambulatory blood pressure monitoring may discontinue a study due to the discomfort and sleep disturbances caused by the device.104 However, a recording with at least eight awake and four sleep readings may be sufficient to give a valid result in a research setting.105 Other drawbacks peculiar to ambulatory blood pressure monitoring include limited availability of the device due to cost, and challenges with reproducibility, particularly in the absence of standardised procedures. Like most automated devices, the presence of arrhythmia, high body mass index and reaction to the environment where the monitoring is performed may affect the results of the ambulatory blood pressure monitor.

Notably, an ambulatory blood pressure monitor may also be used in combination with an ambulatory electrocardiogram (Holter monitoring) to discern blood pressure patterns as well as to ascertain the presence and type of cardiac arrhythmia that may predate an adverse event. For instance, Vasomedical-Biox Model 2301 system is a combined ambulatory electrocardiogram and blood pressure recorder approved by the US Food and Drug Administration.106

Doppler blood pressure-measurement device

Reflection of a sound wave by blood flow is the fundamental principles of Doppler studies. A Doppler probe (made of piezoelectric crystals) is placed on the skin where a vessel such as the brachial artery transverse will produce a sound wave that is reflected back by the distortion of blood flow and/or oscillating arterial wall. This generates changes in frequency (Doppler effect) that are detected by the transducer and used for the assessment of blood pressure.

The use of Doppler for the assessment of blood pressure is important in low-pressure structures where there may be vascular insufficiency,107 shocked patients and children. It may also be valuable in a noisy environment.108 The use of Doppler for routine measurement of blood pressure in pregnancy has not been extensively studied and its accuracy is difficult to confirm or refute.

Blood pressure devices validated in pregnancy

To ensure that an accurate blood pressure reading is obtained, an automated device should be validated, pass a baseline check and/or have an equivalent listing. For instance, Mindray iMEC12 patient monitor (an automated blood pressure device) was listed by the British and Irish Hypertension Society as being suitable for clinical usage. This stems from the fact that Mindray iMEC12 patient monitor was a derivative of Mindray BeneView T5 (a device previously validated).107

A baseline check involves comparing the readings of an unvalidated automated device with those of a mercury or a calibrated aneroid sphygmomanometer.107 A comprehensive description on how to conduct such a baseline check was recently described. To date, not all automated devices have been validated, especially in pregnancy and PE. Details of some blood pressure devices validated in pregnancy and PE that are listed in the dabl Education Trust website,108 the British and Irish Hypertension Society website,107 and those validated without protocol violation107 are listed in Table 2.

It is important to note that at any particular blood pressure range, the accuracy of a blood pressure reading is dependent on the type of blood pressure device (whether or not the device is validated and calibrated) and the adherence to recommended techniques on how to use the device. However, the invasive blood pressure devices may be more accurate than the non-invasive devices,107 but further studies are required to confirm this across devices and different clinical conditions.

General precautions on blood pressure measurement in pregnancy

To minimise the aorta–caval compressive effect of the gravid uterus in a supine position, the blood pressure of pregnant
women should be measured in a sitting position. If this is not possible, the left lateral decubitus position may be used. There is a concern that the left lateral position may falsely lower the blood pressure because the cuff will be above the level of the heart.\textsuperscript{111}

Manufacturer’s instructions should also be given due consideration to ensure proper usage of the blood pressure device. In the same vein, it is advised that newly employed healthcare practitioners should be inducted on how to use equipment (including blood pressure devices) available in their new place of work. Adherence to the institutional protocol is strongly recommended.

Taking only a single blood pressure reading without repeating the measurement may lead to error. This is because a spurious reading and/or anxiety may falsely elevate the first blood pressure measurement.\textsuperscript{7} Recent organisational guidelines suggest that the first reading should be discarded and the average of an additional two readings be regarded as the patient’s blood pressure.\textsuperscript{71} Additionally, the FIGO Textbook of Pregnancy Hypertension: An Evidence-based Guide to Monitoring, Prevention and Management\textsuperscript{6} recommends that when an auscultatory device is used, the first reading should be discarded and the average of the second and third measurements should represent the blood pressure value. With an automated device, the same literature recommends that a total of two measurements should be performed and the average taken as the blood pressure value.\textsuperscript{7} The important message is that at least two to three blood pressure measurements should be taken to improve accuracy.

Since in many health facilities, the most popular equipment used for blood pressure measurement is either an automated or auscultatory device, an evidence-based technique of auscultatory and automated blood pressure measurement is presented in Table 1. The information therein has been reduced in size, making it handy to be utilised in a health facility for easy referencing.

**Further care of patients with abnormal blood pressure**

An abnormal blood pressure should alert clinicians to take further actions directed by institutional and national guidelines or other guidelines endorsed by the health facility. Examples of such guidelines include the Maternity Care Guidelines in South Africa and the international practice recommendations of the ISSHP.\textsuperscript{114}

Treatment of severe high blood pressure: a systolic blood pressure $\geq 160$ mmHg and/or a diastolic blood pressure $\geq 110$ mmHg in pregnancy is regarded as severe hypertension and constitutes an emergency.\textsuperscript{117} Persistence of severe hypertension after 15 minutes requires administration of a first-line rapid-acting antihypertensive drug (such as immediate-release oral nifedipine, intravenous labetalol or dihydralazine) to reduce the blood pressure.\textsuperscript{116,118,121} Administration of magnesium sulphate to prevent eclampsia may also be required.\textsuperscript{112} An expeditious, controlled reduction of blood pressure, commenced within 30 to 60 minutes of confirmed diagnosis, is required to prevent maternal stroke.\textsuperscript{113} The immediate target blood pressure in such an emergency is $140-150/90-100$ mmHg, which prevents prolonged exposure to severe systolic hypertension that may result in a loss of autoregulation of cerebral vasculature.\textsuperscript{114} In fact, it has been shown through 28 case series of maternal stroke associated with pre-eclampsia with severe features (or eclampsia) that the presence of severe systolic hypertension was commoner than severe diastolic hypertension just prior to occurrence of the stroke.\textsuperscript{115}

Assessment of myocardial performance: importantly, there may also be a need to assess myocardial performance, given that blood pressure is a function of cardiac output. The assessment of myocardial performance includes global and regional measures. The traditional measures include assessment of left ventricular ejection fraction and left ventricular mass. However, with a Doppler echocardiography, the global haemodynamic status of the ventricular function may be obtained and the indices include: myocardial performance index (MPI) or Tei index, rate of increase in pressures inside the left ventricle during systole (dP/dT), stroke volume, and cardiac output.\textsuperscript{116} On the other hand, the indices for the assessment of regional ventricular systolic function include: (1) those that assess the wall motion such as wall-motion score index, qualitative and/or semi-quantitative assessment of regional wall; and (2) those that assess systolic cardiac mechanics and deformation such as tissue Doppler imaging (TDI) techniques and/or speckle-tracking imaging (STI).\textsuperscript{117} It is pertinent that these specialised investigations are performed by a trained medical technologist and interpreted by an experienced clinician or cardiologist.

**Challenges associated with blood pressure measurement in pregnancy and HDP**

The challenges associated with blood pressure measurement during pregnancy may be divided into manufacturer-, patient-, health system- and health worker-related factors.

Manufacturer-related factors: some blood pressure-measuring devices on the market do not give an accurate reading in pregnancy.\textsuperscript{112} It is necessary for the manufacturers of blood pressure-measuring devices to test their products in pregnancy conditions prior to marketing. Validation of the accuracy of these devices by independent experts is also recommended. The product/manufacturer’s insert or instructions should specify the limitations of the device indicating if accuracy in pregnancy has been established.

Patient-related factors: cultural beliefs interfere with patients’ acceptance of appropriate techniques of blood pressure measurement.\textsuperscript{115} Ongoing public health education will assist in solving this challenge.

Health system-related factors: these include lack of access to healthcare services, unavailability of approved devices and cuff,\textsuperscript{116} and lack of training of new employees on how to use the devices in their current workplace. To address these issues, policy development and implementation are required. Such policies include those related to procurement of appropriate hospital equipment, the maintenance of these gadgets, organisation of induction courses for new employees and periodic hands-on patient-simulated continuous medical education for medical staff. Support for research and innovative ideas will also facilitate the development of ‘error-free’ devices.

Healthcare professional-related factors (inappropriate technique): these include inadequate patient preparation such as counselling, inappropriate patient position, and failure to consider co-morbidities such as prosthetic heart valves and arteriosclerosis.\textsuperscript{117} Other notable operational errors (including
last-digit error and missing of auscultatory gaps), incorrect patient posture (such as crossed leg during measurement), and an insufficient number of measurements before concluding on the blood pressure value. The frequency of use of a single measurement has been estimated to be 96%, and this may increase the mean blood pressure by 8 mmHg. Conversation during measurement occurs in 41% of cases and results in up to 20% increase in both systolic and diastolic blood pressure. Crossed leg occurs in 15% of measurements and increases the systolic blood pressure by 2–8 mmHg. The key messages are presented in Table 3.

**Conclusion**

The measurement of blood pressure in pregnancy and in HDP requires careful consideration of physiological changes in pregnancy and a need to be mindful of acute severe systolic and/or diastolic hypertension. An appropriate device must be used to ensure that an accurate blood pressure reading is obtained. Poor technique will lead to medical error. Manufacturer-, patient-, health system- and healthcare professional-related challenges that affect blood pressure measurement in pregnancy and HDP need to be addressed, and the recommendations provided in the current review may be helpful to clinicians and healthcare administrators.

**References**


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