

Blood pressure measurement – an overview

Thomas Dieterle

Medical Outpatient Department, University Hospital Basel, Switzerland

Summary

Arterial hypertension continues to represent the leading cause of morbidity and mortality world-wide. Diagnosis and therapy of arterial hypertension require adequate blood pressure measurements. Blood pressure is affected by constitutional and environmental factors as well as the measurement procedure itself, inducing substantial uncertainty with regard to adequate diagnosis and control of arterial hypertension. Therefore, current guidelines recommend that the diagnosis of arterial hypertension should not be solely based on conventional blood pressure measurements in the physician's office or in the hospital, but also on out-of-office ambulatory or home blood pressure measurements using clinically validated semi-automated or automated blood pressure measurement devices.

Despite the enormous progress in the field of arterial hypertension, many aspects of blood pressure measurement require further intensive investigation, for example blood pressure measurement in special populations and distinct clinical situations, as well as the applicability and validation of novel measurement approaches and devices.

This article provides an overview of current methods and trends in the field of non-invasive blood pressure measurement, an update on current clinical guidelines and an overview of blood pressure measurement in special populations.

Key words: *blood pressure measurement; office blood pressure; ambulatory blood pressure; home blood pressure; blood pressure measurement in special populations*

Introduction

According to the recent Global Health Risks Report by the World Health Organisation, arterial hypertension remains the leading cause of morbidity and mortality world-wide [1, 2]. Despite enormous progress in medical science, the diagnosis and therapy of arterial hypertension continue to rely primarily on non-invasive blood pressure (BP) measurements. BP measurements were first reported in the late 18th century. In 1773, Reverend Stephen Hales cannulated the carotid artery of a supine, but un-anesthetised, horse and connected it to a vertical glass tube. The blood rose to a level of about 2.85 m, corresponding to a BP of about

213 mm Hg [3]. This experiment represented one of the first documented measurements of BP in the history of medical research.

Multiple developments for both direct and indirect BP measurement have been made since then. These included the description of an air-filled BP cuff linked to a sphygmomanometer by Scipione Riva-Rocci in 1896 [4] as well as the description of the auscultatory sounds by Korotkoff [5]. These methods allowed a broad application of BP measurements in the population. Even today, routine BP measurements as well as epidemiological and therapeutic studies in the field of arterial hypertension are based on these very early ground-breaking inventions and observations.

The goal of this article is to provide an overview of current methods and trends in the field of non-invasive BP measurement, an update on current guidelines and an overview of BP measurement in special populations.

Non-invasive techniques of blood pressure measurement

Auscultatory blood pressure measurement

The standard sphygmomanometric technique for indirect BP measurement, using a BP cuff linked to a mercury column and applying the Korotkoff sounds phase 1 and 5, has provided the basis for cardiovascular risk stratification and clinical decision making for decades. The methodological approach has been well described [6] and validated against intra-arterial BP measurements [7]. Interestingly, average differences between the sphygmomanometric and the intra-arterial method range from 0.9 to 12.3 mm Hg for systolic BP and from 8.3 to 18 mm Hg for diastolic BP [7]. Among other reasons, observer errors, digit preferences, lack of attention, too rapid cuff deflation, and hearing deficits may account for these substantial inaccuracies [8]. Nevertheless, as there is no better alternative, non-invasive BP measurement using the sphygmomanometric technique continues to be the gold-standard for BP measurement, both in clinical research and clinical practice.

Oscillometric blood pressure measurement

Due to their convenience, safety, the potential for use for BP self measurements and because mercury is progressively banned from use in industry and health care, automatic oscillometric devices are gradually replacing the cuff/

stethoscope method. However, measuring BP oscillometrically remains an engineering challenge. Devices must be able to detect small BP changes within the cuff oscillations over a broad spectrum of much higher cuff pressures necessary to compress the artery during the measuring process. Figure 1 demonstrates the principle of oscillometric BP measurements. Systolic BP (SBP) is measured by an increase in cuff oscillation when blood first passes the deflating cuff. Diastolic BP (DBP) is recognised when oscillations return to baseline. Mean BP corresponds to the maximal oscillations during cuff in and deflation. While mean BP is relatively easy to determine, measurement of systolic and diastolic BP requires sophisticated algorithms for the analysis of the rate of change of amplitude as well as the change in the waveform of oscillations. Additional problems such as irregular cardiac rhythm, variations in cuff deflation rate, and variations in the compressibility of the artery exist, potentially introducing further clinically important measurement errors. Therefore oscillometric devices for office, hospital, home, and ambulatory BP measurements should be validated according to established national and/or international validation protocols (table 3). A list of validated oscillometric devices is published and regularly updated on www.dableducational.org, on the website of the British Hypertension Society (www.bhsoc.org), as well as on the websites of the Swiss and German Hypertension Societies (www.swisshypertension.ch, www.hochdruckliga.de).

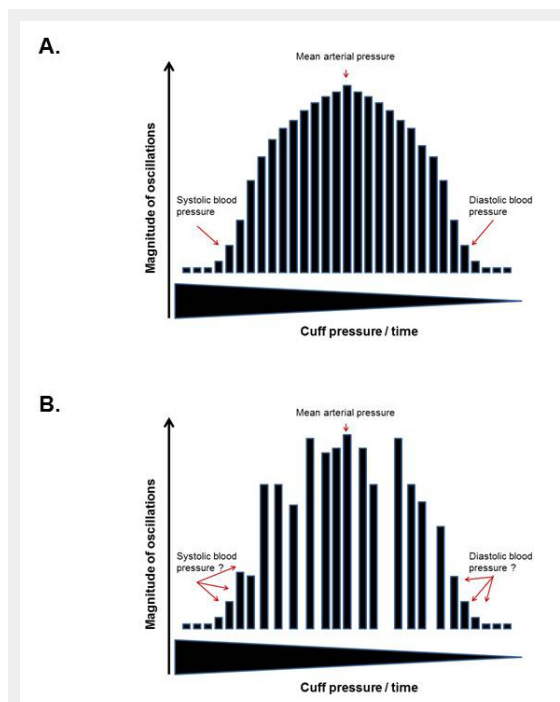


Figure 1

Oscillometric blood pressure measurement (technical principle). A Decreasing cuff pressure allows continuous increase of blood flow with consecutive increase in oscillation amplitude. When reaching mean arterial BP, amplitude of oscillations decreases. Estimation of systolic and diastolic BP depends on algorithms designed by the manufacturer of the device.

B Arrhythmia leads to changing ventricular filling with consecutively alternating pulse pressure and alternating magnitude of oscillations, rendering determination of systolic and diastolic BP difficult at the least, if not impossible.

Measurement of central aortic blood pressure

Due to progressive stiffening of the peripheral arterial walls, progressive reduction of the arterial diameter, and reflecting pulse waves amplifying peripheral BP, peripheral systolic BP is higher and diastolic BP is lower than central BP [9]. However, central aortic pressure, particularly central aortic pulse pressure, appears to predict cardiovascular and central nervous risk better than peripheral BP [10, 11]. In addition, calculations of cardiac work may be derived from central aortic pressure. Currently, four methods have been described for the non-invasive determination of central aortic BP. In general, these methods rely on arterial applanation methods either combined with the use of mathematical transfer functions and/or conventional BP measurement [8]. However, due to the time, experience, and financial investment that are required for the measurements as well as the lack of a broader validation using parallel intra-arterial measurements, determination of central aortic BP does not appear to be currently suitable for routine clinical use.

Other non-invasive methods of blood pressure measurement

Further methods for non-invasive assessment of BP have been developed using ultrasound techniques and photo-plethysmographic methods. In principle, ultrasound techniques measure the movement of the arterial wall. Systolic BP is determined by a Doppler phase shift in the reflected ultrasound, while diastolic BP is determined by diminution of arterial wall motion. Another variation of this method detects the onset of blood flow at systolic pressure. This approach has been found to be of particular value for measuring pressure in infants and children and in patients with very faint Korotkoff sounds. In addition, this method can be applied to determine ankle-brachial-index (ABI), in which the systolic pressures in the brachial artery and the posterior tibial artery are compared to obtain an index of peripheral arterial disease [12].

The Finger Cuff Method of Penaz is a photo-plethysmographic method for continuous assessment of BP. In principle, plethysmographic output is used to drive a servo-loop, which rapidly changes the cuff pressure to keep the output constant and to hold the artery in a partially opened state. Cuff oscillations are closely correlated to the intra-arterial pressure wave, giving an accurate estimate of the changes of systolic and diastolic pressure [12].

How to correctly measure blood pressure

General aspects

BP is characterised by large spontaneous variations both during the day and between days, months and seasons [13–15]. In addition, BP is affected by the circumstances of measurement itself, including emotion, exercise, meals, tobacco use, alcohol intake, temperature, respiration, bladder distension and pain. Moreover, age, race and diurnal variation play an important role, and have to be taken into account when judging BP values. Therefore, the diagnosis of arterial hypertension should usually be based on mul-

multiple BP measurements, taken on separate occasions. In patients with only slightly elevated BP, repeated measurements should be obtained over a period of several months to accurately define “usual” BP values. In cases of markedly elevated BP, evidence of hypertension-related organ damage or a high or very high cardiovascular risk profile, repeated measurements should be obtained within weeks or days. BP can be measured by the doctor or the nurse in the office or in the clinic, by the patient or a relative at home, or automatically over 24 h [16, 17]. The currently recommended cut-off values for the different modalities of BP measurement are summarised in table 1.

Office blood pressure measurement (OBPM) [16]

BP in the office can be measured using a mercury sphygmomanometer and another non-invasive semi-automated or automated oscillometric device. As outlined above, oscillometric devices will become increasingly important because of the progressive banning of the medical use of mercury. Again, it is mandatory that these devices should be validated according to standardised protocols and their accuracy should be checked periodically. Measurements should be performed in a quiet environment with the patient having been seated for several minutes. At least two measurements spaced by 1–2 minutes should be taken. Additional measurements should be considered if the first two differ by more than 5–10 mm Hg. A standard bladder (12–16 cm wide and 26–30 cm long) should be routinely used. However, a larger and a smaller bladder must be used for fat and thin arms, respectively (table 2). Independent from the patient’s position, the BP cuff has to be placed at the heart level. Phase 1 (first appearance of faint, repetitive, clear tapping sounds that gradually increase in intensity),

and phase 5 (disappearance of tapping sounds) Korotkoff sounds are used to identify systolic and diastolic BP.

Measurement should be taken in both arms at the first visit to detect possible differences due to peripheral vascular disease. In this case, the higher value should be taken as reference. ESH/ESC guidelines recommend to take standing BP one and five minutes after assumption of the standing position in elderly subjects, diabetic patients, and in patients with other conditions in which postural hypotension may be frequent or suspected [1]. Heart rate should be measured after the second measurement in the sitting position [1].

Recent data suggest that repeated OBPM every 5 minutes over a period of 30 minutes may be equivalent to ambulatory BP measurement (ABPM) in terms of classification in normotension, white-coat hypertension, masked hypertension, and sustained hypertension [18].

Ambulatory blood pressure measurement (ABPM, [16])

Multiple, mostly oscillometric, devices are available for ABPM. They provide information on 24-hour average BP as well as on mean values over defined periods of time such as the day, night or morning while the patient is able to conduct a normal life. ABPM correlates more closely with hypertension-related organ damage and its changes by treatment than does OBPM [19]. Reproducibility of measurements and prediction of cardiovascular risk is greater than with OBPM [20], and ABPM more accurately reflects the effects of BP reduction induced by treatment. ABPM provides information on both daytime and night-time BP profiles, day-night BP difference, morning BP rise and BP variability. Though information obtained by ABPM should currently not be regarded as a substitute for information de-

Table 1: Reference values for the diagnosis and exclusion of arterial hypertension.

Modality of BP measurement	Average SBP	Average DBP
Office or clinic	140 mm Hg	90 mm Hg
24-hour	125–130 mm Hg	80 mm Hg
– Day	130–135 mm Hg	85 mm Hg
– Night	120 mm Hg	70 mm Hg
Home	130–135 mm Hg	85 mm Hg

Modalities of BP measurements are given together with reference values respectively ranges according to ESH/ESC guidelines for the management of arterial hypertension (BP, blood pressure; SBP, systolic BP; DBP, diastolic BP).

Table 2: Recommended cuff bladder sizes for the measurement of blood pressure (modified from [48]).

Children			
	Width (cm)	Length (cm)	Maximum arm circumference (cm)
Newborn	4	8	10
Infant	6	12	15
Child	9	18	22
Adults (British Hypertension Society)			
Cuff type	Width (cm)	Length (cm)	Patient group
Small	12	22	Lean adult arms and children
Standard	12	26	Most adult arms
Large	12	40	Arms of obese patients
Adults (American Heart Association)			
Cuff type	Width (cm)	Length (cm)	Arm circumference (cm)
Small adults	12	22	22–26
Adults	16	30	27–34
Large adults	16	36	35–44
Adult thigh	16	42	45–52

rived from OBPM, a recent meta-analysis suggests ABPM as the reference standard to avoid misdiagnosis of arterial hypertension and to allow for a more targeted anti-hypertensive drug therapy [21]. It is important to note that normal ABPM values differ from reference OBPM values (table 1).

Indications for ABPM include

- confirmation of the diagnosis of arterial hypertension;
- suspected white-coat hypertension;
- suspected nocturnal hypertension;
- suspected masked hypertension;
- establishment of dipper status;
- resistant hypertension;
- hypertension of pregnancy [1, 16].

Further potential indications include BP measurements in elderly patients, as a guide to antihypertensive therapy [22], diabetes mellitus, evaluation of symptoms suggesting hypotension, and autonomic failure. Moreover, ABPM should be considered when substantial variability is found for repeated OBPM, when high office BP is found in the absence of hypertension-related target organ damage or vice versa [1, 17]. A further indication for ABPM may arise from a recent observation that a substantial proportion of patients with apparently controlled arterial hypertension, according to OBPM, have elevated ABPM values [23].

As for OBPM, care should be taken to use appropriate cuff sizes for ABPM. Readings should be taken every 10–15 minutes during the day and every 30 minutes during the night. At least two thirds of measurements should be of satisfactory quality. The patient should be instructed to perform the usual daily activities. Keeping record of unusual activities and events allows for more accurate diagnosis. To date, clinical judgment should be based on average 24h, daytime, and night-time BP values.

Self/home blood pressure measurement (HBPM) [16]

HBPM has gained considerable popularity among patients for its general availability and ease of use. Though HBPM appears to be inferior to ABPM with regard to the diagnosis of arterial hypertension [21], diagnostic sensitivity of HBPM appears to be higher and prognostic value improved compared to OBPM [21, 24]. In addition, HBPM may improve BP control [1]. Despite the fact that further research is needed to readily establish the precise role of HBPM for the diagnosis and treatment of arterial hypertension, indications for HBPM are similar to the indications for ABPM [16] and HBPM may even be used to substitute ABPM in case the latter is not tolerated [17].

Devices for HBPM should be validated according to national and international guidelines (table 3). Currently, most devices designed for BP measurements at the upper

arm fulfil the validation requirements. In contrast, there are considerably less devices for blood wrist pressure measurements that are validated for clinical use. Devices for BP measurement at the finger cannot be recommended currently.

As for OBPM and ABPM, it is mandatory to use adequately sized BP cuffs for HBPM. The principles for HBPM do not vary from the recommendations for OBPM. Measurements should be performed in a quiet environment in a sitting position after at least five minutes of rest. In the initial phase of assessment or at initiation of treatment, two BP measurements should be taken daily in the morning as well as in the evening for a period of one week. Recent data suggest that five, or even as little as three, days might be sufficient for the diagnosis of arterial hypertension [25, 26]. Devices equipped with a memory may be beneficial to insure documentation and quality of measurements. For long-term observations, this routine can be reduced to one week per quarter.

Diagnosis of arterial hypertension

General aspects

In general, the diagnosis of hypertension should be based on at least 2 OBPM per visit and at least 2 to 3 visits. In severe cases the diagnosis may be based on measurements taken at a single visit [1, 27]. As outlined above, BP will always be a variable hemodynamic phenomenon that is influenced by many factors. However, OBPM may not discover all patients with arterial hypertension such as patients with so-called “masked hypertension”. Moreover, OBPM may erroneously identify patients as sustained hypertensives who present with elevated BP in the office – a situation named “white-coat hypertension”. Both the phenomena of white-coat hypertension and masked hypertension underline the importance of performing out-of-office BP measurements.

Diagnostic thresholds for OBPM, ABPM, and HBPM

Diagnostic thresholds for the diagnosis of arterial hypertension using different diagnostic modalities are given in table 1. Taking into account both OBPM and ABPM, individual BP values can be classified into normotension, white-coat hypertension, masked hypertension and sustained hypertension.

Normotension, controlled hypertension

In normotensive patients and patients with adequately controlled hypertension, both OBPM and ABPM, and HBPM are below the thresholds given in table 1.

Table 3: Generally recognised protocols for clinical validation of blood pressure monitors.

Protocol	Validation results	Clinically usable
AAMI	Pass / Fail	Pass
BHS	A – D	A, B
DHL	Approved / not approved (Prüfsiegel erteilt / nicht erteilt)	Approved (Prüfsiegel erteilt)
ESH	Pass / Fail	Pass

Validation protocols according to publications by the AAMI (American Association for the Advancement of Medical Instrumentation [7]), BHS (British Hypertension Society [49]), DHL (Deutsche Hochdruck-Liga (German Hypertension Society) [50]), and the ESH (European Society of Hypertension [51]).

Sustained hypertension, uncontrolled hypertension

The term “sustained hypertension” refers to the “truly hypertensive” population. In these patients both BP values obtained from OBPM and ABPM, and from OBPM and HBPM, are elevated. The same applies to patients with so-called uncontrolled hypertension, which means patients that do not have hypertension adequately controlled with their current anti-hypertensive medication.

White coat hypertension

Many hypertensive patients exhibit BP values obtained by OBPM that are higher than BP values obtained outside the medical environment (e.g., by ABPM or HBPM). While this phenomenon is named “white-coat effect”, the term “white-coat hypertension (or isolated clinical hypertension)” denominates hypertensive BP values with OBPM and normal BP values with ABPM or HBPM [15]. Isolated office hypertension may be present in about 15% of the general population and may account for one third or more of individuals in whom hypertension is diagnosed [28, 29]. It is especially prevalent in elderly patients, pregnant women, and patients, particularly elderly, with advanced chronic kidney disease [1]. The cardiovascular risk appears to be lower than in individuals with both raised office and ambulatory BP [1]. However, a comparable prevalence of target-organ damage and metabolic abnormalities has been described in this population, indicating that white-coat hypertension (WCH) may not be a clinically innocent phenomenon [27].

Masked hypertension

The term “masked hypertension” (MH) refers to the observation of a normal OBPM together with an increased BP outside the physician’s office. The prevalence of this condition appears to be comparable to the prevalence of white-coat hypertension [29]. About 1 in 7 or 8 subjects with a normal office BP may fall into this category [28]. Although data on this condition is sparse, there is evidence of a greater than normal prevalence of hypertensive target-organ damage [30], an increased prevalence of metabolic abnormalities [28] compared with entirely normotensive subjects indicating increased cardiovascular risk, which appears to be close to that of in- and out-of-office hypertensive patients [31].

Exercise-induced hypertension

The auscultatory BP measurement method may underestimate systolic BP during exercise while it may be overestimated during recovery [12]. Measurement of diastolic BP appears to be more accurate. However, false low diastolic readings may be recorded during recovery, indicating that Korotkoff sound phase 4 should be used in this setting. Exaggerated BP response to exercise (>2 SD increase during exercise), 6-min exercise systolic BP as well as maximal exercise-induced BP were all predictive for cardiovascular mortality [32]. Nevertheless, a cut-off for the diagnosis of arterial hypertension remains to be defined. For practical purposes, exercise-induced systolic BP values ≥ 180 mm Hg and/or diastolic BP values ≥ 100 mm Hg at step 2 of the Bruce protocol (≈ 120 W) respectively systolic BP values ≥ 210 mm Hg/190 mm Hg (men/women) at maximal exer-

cise have been proposed as diagnostic criteria for exercise-induced hypertension [33].

Blood pressure measurement in special populations

Children and adolescents

Several recent studies have demonstrated that paediatric hypertension, particularly in adolescents, is not as uncommon as was previously believed. Its prevalence is increasing in parallel to the paediatric obesity epidemic [34, 35]. Conventional OBPM remains the cornerstone for the diagnosis of paediatric hypertension. However, as both WCH and MH exist in this population as well, assessment of out-of-office BP by ABPM or HBPM is essential for a precise diagnosis. As in adults, the choice of the correct cuff size is mandatory. The length of the bladder should cover 80–100% of the individual’s arm circumference [36]. Oscillometric devices including devices for ABPM and HBPM should only be used when validated in a paediatric population.

Due to the extremely long follow-up, in children only data exist for the association of ABPM with surrogate markers of hypertensive target organ damage [37]. Data on HBPM, especially on reproducibility, clinical application, and diagnostic value compared to OBPM and ABPM, are sparse. The currently recommended thresholds for the diagnosis of paediatric hypertension are given in table 4A. Table 4B shows a simple “rule of thumb” obtained from the guidelines of the Swiss Hypertension Society for rapid determination of paediatric BP thresholds. Further information on the European recommendations on BP thresholds and the management of high BP in paediatric patients can be obtained from [38, 39]. However, more research on the normal range of OBPM, ABPM, and HBPM and their association with hypertensive target-organ damage is urgently needed.

Pregnant women [40]

Hypertensive disorders during pregnancy are among the leading causes for maternal and foetal morbidity and mortality. They account for more than 50’000 maternal deaths per year.

Of greatest clinical importance is preeclampsia, characterised by hypertension, proteinuria, and/or organ dysfunction, complicating 2–5% of all pregnancies [41]. Severe consequences of preeclampsia include eclampsia and the HELLP-syndrome (haemolysis, elevated liver enzymes, low platelet count). Therefore, early diagnosis of arterial hypertension during pregnancy is of major importance. Criteria for hypertension disorders of pregnancy are:

- Two or more readings with systolic BP ≥ 140 mm Hg and/or diastolic BP ≥ 90 mm Hg over a period of 4–6 hours after 20 weeks of gestation;
- Korotkoff phase 5 sounds define DBP, in case DBP equals 0, Korotkoff phase 4 sounds (muffled, soft sounds following crisp and loud Korotkoff phase 3 sounds) may be applied;
- ABPM or HBPM should be performed if WCH or MH is suspected.

Elderly patients

As in younger patients BP should be measured while seated, and two or more measurements should be averaged. As outlined above, BP should routinely be taken in standing position because elderly patients in particular may have postural hypotension [42]. The prevalence of WCH, isolated systolic hypertension, and pseudohypertension appears to be higher in elderly patients. Hypotension is more common in diabetic patients, especially in the morning and after meals. HBPM as well as ABPM may be helpful for the diagnosis as well as the titration of antihypertensive therapy.

Obese patients [42]

The correct choice of the cuff size is needed for adequate compression of the upper arm. The use of inadequately (i.e. too small) sized cuffs may result in considerable overestimation of BP in obese patients. In case, Korotkoff sounds cannot be auscultated, palpation of the appearance of the radial pulse and auscultation of the radial artery pulsation may help in estimating BP.

Patients on haemodialysis

Hypertension is a frequent observation in haemodialysis patients, reaching a prevalence of 70–80% (office pre-dialysis BP), and is associated with a very high cardiovascular risk [43]. While there is an elevation of systolic BP, diastolic BP decreases, resulting in an elevated pulse pressure. In chronic kidney disease a target BP of <130/80 mm Hg is usually recommended [44], but the appropriate target BP in haemodialysis patients remains to be defined. Moreover, there is no consensus on the optimal timing of BP measurements ensuring adequate diagnosis of hypertension in this population.

In haemodialysis patients, association between post-dialysis BP and (peripheral and cerebral) vascular mortality appears to follow a U-shaped relationship. A significant increase of cardiovascular risk was observed when systolic BP was >180 mm Hg or <110 mm Hg [45]. Nevertheless, post-dialysis BP measurement rather than pre-dialysis BP measurements were found to be independently correlated with mortality [46]. As OBPM is considerably influenced by the dialysis session *per se*, by the speed of volume removal as well as by counter-regulatory responses, ABPM has been generally considered to be superior to the classical BP measuring method to assess hypertension in chronic

haemodialysis patients. A criterion for the classification of hypertension in this patient group has been proposed based on 44-h inter-dialytic BP measurements. Despite a lack of evidence from outcome trials, pre-dialytic office BP values >150/85 mm Hg and post-dialytic >130/75 mm Hg are considered to represent a hypertensive BP [47]. Evidence for the usefulness of HBPM in this population remains to be established. As for OBPM and ABPM, neither diagnostic thresholds nor therapeutic targets have been established so far.

Conclusions

Non-invasive BP measurements remain the mainstay for the diagnosis of arterial hypertension, an aid for non-invasive estimation of hemodynamic status, stratification of overall cardiovascular risk and the guidance for anti-hypertensive therapy. Despite the use of, in part, very sophisticated technology, BP measurement in research and the clinical setting continues to be based on basic principles described by Riva-Rocci [4] and Korotkoff [5].

Comprehensive evaluation of BP requires measurement of BP in the physician's office and the hospital. The diagnosis of arterial hypertension should be confirmed by evaluation of BP outside the medical environment using either ABPM or, if ABPM is not tolerated, HBPM [17]. Only the combination of in- and out-of-practice/hospital methods allows a definite diagnosis of normotension, sustained, white-coat or masked hypertension and the judgment of whether BP is adequately controlled in treated patients.

Though not definitely defined yet, both ABPM and HBPM appear to be more closely correlated to target-organ damage and prognosis in the hypertensive population. However, neither BP stages nor treatment target values have been derived from epidemiological studies so far. In addition, substantial uncertainty exists with regards to adequate methodology of BP measurement as well as BP thresholds and target values in special populations, such as elderly patients or patients on haemodialysis. Future studies will have to take into account these important issues.

In summary, non-invasive BP measurement is an easy-to-perform and powerful method for cardiovascular risk stratification in the population. However, further research is necessary to refine current BP methods and to answer important questions regarding BP measurement methodology and treatment effects in special populations.

Table 4A: Thresholds for the diagnosis / exclusion of arterial hypertension in children and adolescents.

	OBPM	ABPM	HBPM
Normal BP	<90 th percentile	–	–
High-normal BP	90 th – <95 th percentile or ≥120/80 mm Hg	–	–
Hypertension Stage 1	95 th – 99 th percentile + 5 mm Hg	≥95 th percentile	≥95 th percentile
Hypertension Stage 2	>99 th percentile + 5 mm Hg		

Table 4B: "Rule of thumb" for the determination of blood pressure thresholds for the diagnosis of arterial hypertension in children and adolescents [39].

Age (years)	Systolic Hypertension
1–17	>100 + (Age x 2) mm Hg
	Diastolic Hypertension
1–10	>60 + (Age x 2) mm Hg
11–17	>70 + Age mm Hg

OBPM, office BP measurement; ABPM, ambulatory BP measurement, HBPM, home BP measurement.

Funding / potential competing interests: No financial support and no other potential conflict of interest relevant to this article were reported.

Correspondence: Thomas Dieterle, MD, University Hospital Basel, Medical Outpatient Department, Petersgraben 4, CH-4031 Basel, Switzerland, [dieterle\[at\]uhbs.ch](mailto:dieterle[at]uhbs.ch)

References

- The task force for the management of arterial hypertension of the European Society of Hypertension (ESH) and of the European Society of Cardiology (ESC). 2007 guidelines for the management of arterial hypertension. *J Hypertens*. 2007;25:1105–87.
- who.int [homepage on the Internet]. WHO Global Health Risks Report, 2009 [updated 2009; cited 2012 Jan 5]. Available from www.who.int/healthinfo/global_burden_disease/global_health_risks/en/.
- O'Brien E, Fitzgerald D. The history of blood pressure measurement. *J Hum Hypertens*. 1994;8:73–84.
- Riva-Rocci S. Un nuovo sfigmomanometro. *Gaz Med Torino*. 1896;47:981–96.
- Korotkoff NS. On the subject of methods of measuring blood pressure. *Bull Imp Military Med Acad*. 1905;11:365–7.
- Perloff D, Grim C, Flack J, Frohlich ED, Hill M, McDonald M, et al. Human blood pressure determination by sphygmomanometry. *Circulation*. 1993;88:2460–70.
- American National Standard for Electronic or Automated Sphygmomanometers. ANSI/AAMI SP 10-1992. Arlington VA, Association for the Advancement of Medical Instrumentation. 1993, p.12.
- Smulyan H, Safar ME. Blood pressure measurement: retrospective and prospective views. *Am J Hypertens*. 2011;24:628–34.
- Avolio AP, van Bortol LM, Boutouyrie P, Cockcroft JR, McEniery CM, Protogerou AD, et al. Role of pulse pressure amplification in arterial hypertension: experts' opinion and review of the data. *Hypertension*. 2009;54:375–83.
- Benetos A, Safar M, Rudnicki A, Smulyan H, Richard JL, Ducimetière P, et al. Pulse pressure: a predictor of long-term cardiovascular mortality in a French male population. *Hypertension*. 1997;30:1410–5.
- Franklin SS, Khan SA, Wong ND, Larson MG, Levy D. Is pulse pressure useful in predicting risk for coronary artery disease? The Framingham Heart Study. *Circulation*. 1999;100:354–60.
- Ogedegbe G, Pickering T. Principles and techniques of blood pressure measurement. *Cardiol Clin*. 2010;28:571–86.
- Mancia G, Ferrari A, Gregorini L, Parati G, Pomidossi G, Bertinieri G, et al. Blood pressure and heart rate variabilities in normotensive and hypertensive human beings. *Circ Res*. 1983;53:96–104.
- Sega R, Cesana G, Bombelli M, Grassi G, Stella ML, Zanchetti A, et al. Seasonal variations in home and ambulatory blood pressure in the PAMELA population. *Pressione Arteriose Monitorate Associazioni. J Hypertens*. 1998;16:1585–92.
- Modesti PA, Morabito M, Bertolozzi I, Massetti L, Panci G, Lumachi C, et al. Weather-related changes in 24-hour blood pressure profile: effects of age and implications for hypertension management. *Hypertension*. 2006;47:155–61.
- O'Brien E, Asmar R, Beilin L, Imai Y, Mancia G, Mengden T, et al., on behalf of the European Society of Hypertension Working Group on Blood Pressure Monitoring. Practice guidelines of the European Society of Hypertension for clinic, ambulatory and self blood pressure measurement. *J Hypertens*. 2005;23:697–701.
- guidance.nice.org.uk [homepage on the Internet]. NICE clinical guideline 127. Hypertension. Clinical management of primary hypertension in adults [updated 2011 August; cited 2012 Jan 5]. Available from: guidance.nice.org.uk/CG127.
- van der Wel MC, Buonsik IE, van Weel C, Thien TABM, Bakx JC. A novel approach to office blood pressure measurement: 30-minute office blood pressure vs. daytime ambulatory blood pressure. *Ann Fam Med*. 2011;9:128–35.
- Redon J, Baldo E, Lurbe E, Bertolin V, Lozano JV, Miralles A, et al. Microalbuminuria, left ventricular mass and ambulatory blood pressure in essential hypertension. *Kidney Int Suppl*. 1996;55:S81–S84.
- Kikuya M, Ohkubo T, Asayama K, Metoki H, Obara T, Saito S, et al. Ambulatory blood pressure and 10-year risk of cardiovascular and noncardiovascular mortality. The Ohasama Study. *Hypertension*. 2005;45:240–5.
- Hodgkinson J, Mant J, Martin U, Guo B, Hobbs FDR, Deeks JJ, et al. Relative effectiveness of clinic and home blood pressure monitoring compared with ambulatory blood pressure monitoring in diagnosis of hypertension: systematic review. *BMJ*. 2011;342:d3621 doi: 10.1136/bmj.d3621.
- Zaninelli A, Parati G, Cricelli C, Bignamini AA, Modesti PA, Pamparana F, et al., on behalf of MARTE investigators. Office and 24-h ambulatory blood pressure control by treatment in general practice: the 'Monitoraggio della pressione Arteriosa nella medicina Territoriale' study. *J Hypertens*. 2010;28:910–7.
- McGowan N, Padfield PL. Self blood pressure monitoring: a worthy substitute for ambulatory blood pressure? *J Hum Hypertens*. 2010;24:801–6.
- Sheikh S, Sinha AD, Agarwal R. Home blood pressure monitoring: how good a predictor of long-term risk? *Curr Hypertens Rep*. 2011;13:192–9.
- Johansson JK, Niiranen TJ, Puukka PJ, Jula AM. Optimal schedule for home blood pressure monitoring based on a clinical approach. *J Hypertens*. 2010;28:259–64.
- Niiranen TJ, Johansson JK, Reunanen A, Jula AM. Optimal schedule for home blood pressure measurement based on prognostic data. The Finn-Home study. *Hypertension*. 2011;57:1081–6.
- Dieterle T, Sigle JP, Bengel G, Kiefer G, Brenneisen V, Martina B. Cardiovascular risk stratification in unselected primary care patients with newly detected arterial hypertension. *Hypertens Res*. 2010;33:607–15.
- Mancia G, Facchetti R, Bombelli M, Grassi G, Sega R. Long-term risk of mortality associated with selective and combined elevation in office, home, and ambulatory blood pressure. *Hypertension*. 2006;47:846–53.
- Hansen TW, Jeppesen J, Rasmussen S, Ibsen H, Torp-Pedersen C. Ambulatory blood pressure monitoring and risk of cardiovascular disease: a population based study. *Am J Hypertens*. 2006;19:243–50.
- Sega R, Trocino G, Lanzarotti A, Carugo S, Cesana G, Schiavina R, et al. Alterations of cardiac structure in patients with isolated office, ambulatory or home hypertension. Data from the general PAMELA population. *Circulation*. 2001;104:1385–92.
- Bobrie G, Chatellier G, Genes N, Clerson P, Vaur L, Vaisse B, et al. Cardiovascular prognosis of "masked hypertension" detected by blood pressure self-measurement in elderly treated hypertensive patients. *JAMA*. 2004;291:1342–9.
- Kjeldsen SE, Mundal R, Sandvik L, Erikssen G, Thaulow E, Erikssen J. Supine and exercise systolic blood pressure predict cardiovascular death in middle-aged men. *J Hypertens*. 2011;19:1343–8.
- Brenner R, Alleman Y. Pathologische Blutdruckreaktion bei körperlicher Belastung. *Praxis*. 2011;100:1041–9.
- Sorof JM, Lai D, Turner J, Poffenbarger T, Portman RJ. Overweight, ethnicity, and the prevalence of hypertension in school-aged children. *Pediatrics*. 2004;113:475–82.
- Genovesi S, Giussani M, Pieruzzi F, Vigorita F, Arcovio C, Cavuto S, et al. Results of blood pressure screening in a population of school-aged children in the province of Milan: role of overweight. *J Hypertens*. 2005;23:493–7.
- Karpettas N, Kollias A, Vazeou A, Stergiou GS. Office, ambulatory and home blood pressure measurement in children and adolescents. *Expert Rev Cardiovasc Ther*. 2010;8:1567–78.
- Stabouli S, Kotsis V, Zakopoulos N. Ambulatory blood pressure monitoring and target organ damage in pediatrics. *J Hypertens*. 2007;25:1979–86.
- Lurbe E, Cifkova R, Cruikshank JK, Dillon MJ, Ferreira I, Invitti C, et al.; European Society of Hypertension. European Society of Hypertension. Management of high blood pressure in children and adolescents:

- recommendations of the European Society of Hypertension. *J Hypertens.* 2009;27:1719–42.
- 39 [swisshypertension.ch](http://www.swisshypertension.ch) [homepage on the Internet]. 2009 Swiss Society of Hypertension Guidelines [updated 2009; cited 2012 Jan 5]. Available from: www.swisshypertension.ch/guidelines.htm.
- 40 Rath W, Fischer T. The diagnosis and treatment of hypertensive disorders of pregnancy. *Dtsch Arztebl Int.* 2009;106:733–8.
- 41 Report of the National High Blood Pressure Education Program. Working group report on high blood pressure in pregnancy. *Am J Obstet Gynecol.* 2000;183:181–92.
- 42 Pickering TG, Hall JE, Appel LJ, Falkner BE, Graves J, Hill MN, Jones DW, et al. Recommendations for blood pressure measurement in humans and experimental animals. Part 1: Blood pressure measurement in humans. *Circulation.* 2005;111:697–715.
- 43 Charra B, Jean G, Chazot C, et al. Intensive dialysis and blood pressure control: a review. *Hemodial Int.* 2004;8:51–60.
- 44 Mancia G, Laurent S, Agabiti-Rosei E, Ambrosioni E, Burnier M, Caulfield MJ, et al. Reappraisal of European guidelines on hypertension management: a European Society of Hypertension Task. *J Hypertens.* 2009;27:2121–58.
- 45 Zager P, Nikolic J, Brown R, Campbell MA, Hunt WC, Peterson D, et al. “U” curve association of blood pressure and mortality in hemodialysis patients. *Kidney Int.* 1998;54:561–9.
- 46 Mendes R, Santos S, Dorigo D, Mansoor GA, Crowley ST, White WB, et al. The use of peridialysis blood pressure and intradialytic blood pressure changes in the prediction of interdialytic blood pressure in hemodialysis patients. *Blood Press Monit.* 2003;8:243–8.
- 47 Saint-Remy A, Krzesinski JM. Optimal blood pressure level and best measurement procedure in hemodialysis patients. *Vasc Health Risk Manag.* 2005;1:235–44.
- 48 Parati G, Stergiou GS, Asmar R, Bilo G, de Leeuw P, Imai Y, et al. European Society of Hypertension guidelines for blood pressure monitoring at home: a summary report of the Second International Consensus Conference on Home Blood Pressure Monitoring. *J Hypertens.* 2008;26:1505–30.
- 49 O’Brien E, Petrie J, Littler W, de Swiet M, Padfield PL, Altman DG, et al. An outline of the revised British Hypertension Society protocol for the evaluation of blood pressure measuring devices. *J Hypertension.* 1993;11:677–9.
- 50 [hochdruckliga.de](http://www.hochdruckliga.de) [homepage on the Internet]. Prüfsiegel-Protokoll der Deutschen Hochdruckliga [updated 1999; cited 2012 Jan 5]. Available via: www.hochdruckliga.de.
- 51 O’Brien E, Atkins N, Stergiou G, Karpettas N, Parati G, Asmar R, et al. European Society of Hypertension International Protocol revision 2010 for the validation of blood pressure measuring devices in adults. *Blood Press Monit.* 2010;15:23–38.

Figures (large format)

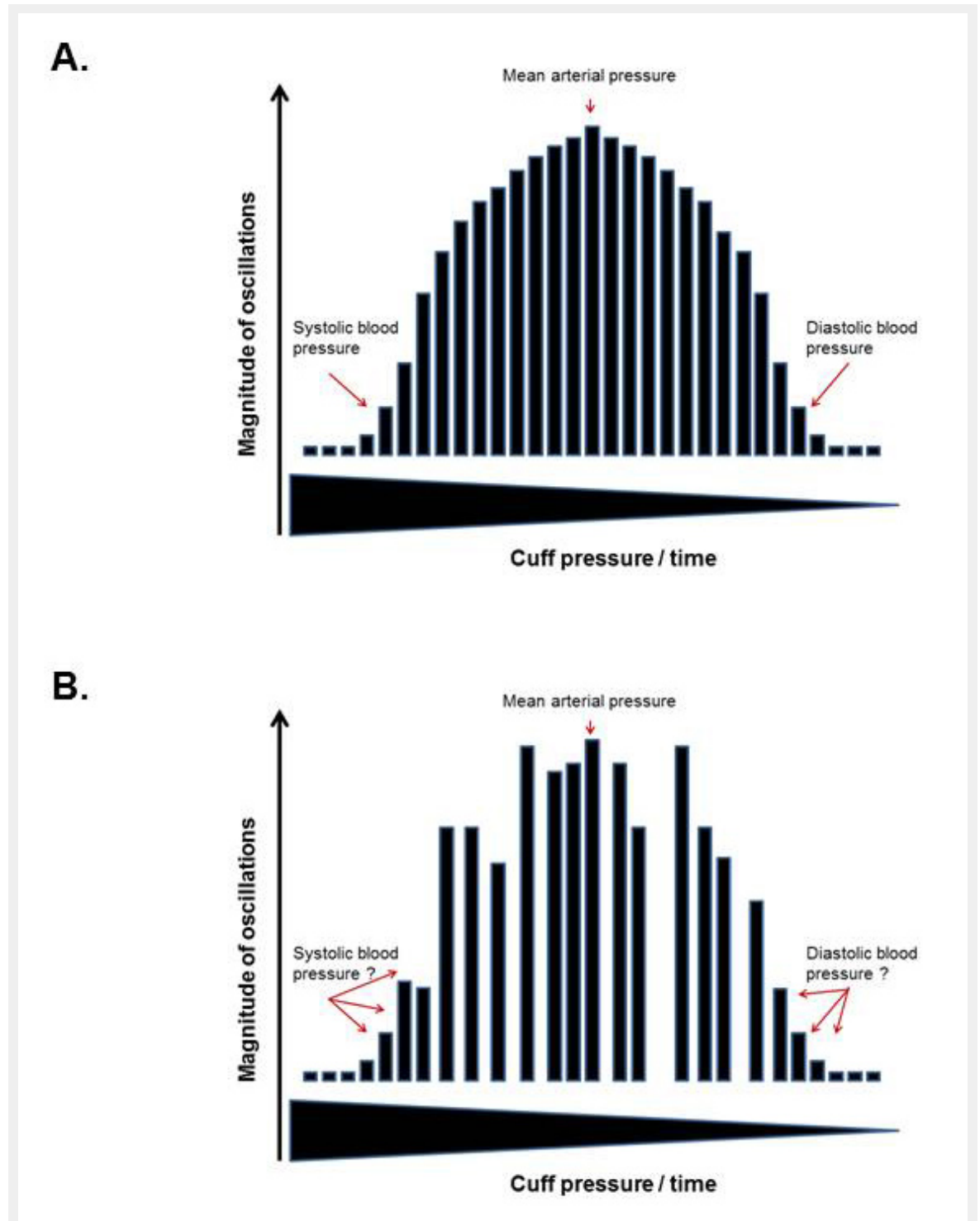


Figure 1

Oscillometric blood pressure measurement (technical principle).

A Decreasing cuff pressure allows continuous increase of blood flow with consecutive increase in oscillation amplitude. When reaching mean arterial BP, amplitude of oscillations decreases. Estimation of systolic and diastolic BP depends on algorithms designed by the manufacturer of the device.

B Arrhythmia leads to changing ventricular filling with consecutively alternating pulse pressure and alternating magnitude of oscillations, rendering determination of systolic and diastolic BP difficult at the least, if not impossible.