

# Consensus document on non-invasive ambulatory blood pressure monitoring

## The Scientific Committee\*

During a conference devoted to problems of non-invasive ambulatory blood pressure monitoring held in Berlin on March 2 and 3 1990, the following issues were intensively discussed and a consensus was reached on certain aspects. A number of devices are now available which may be considered acceptable in terms of accuracy and reliability, patient acceptability, computer compatibility and cost. To standardize data analysis, day and night blood pressure profiles should be analysed, the daytime period running for  $15 \pm 2$  h (7.00 a.m. to 10.00 p.m.) and the night-time for  $9 \pm 2$  h (10.00 p.m. to 7.00 a.m.). Data analysis should provide mean and median systolic, diastolic and mean arterial pressures and heart rates for the daytime, the night-time and the full 24-h period. The results of a meta-analysis of studies on non-invasive ambulatory blood pressure monitoring in healthy and apparently normotensive subjects suggest that a daytime mean blood pressure of  $\geq 135/85$  mmHg may represent a hypertensive condition (the full 24-h mean may be lower). This may be taken as the provisional cutoff level between a normal and a high daytime blood pressure, pending the results of studies from non-selected general populations including untreated hypertensives. Ambulatory blood pressure monitoring appears to be a better predictor of left ventricular hypertrophy than casual blood pressure measurements are. Since increased left ventricular mass is a strong predictor of an adverse prognosis, ambulatory monitoring may also be more predictive of prognosis than casual readings. Non-invasive ambulatory blood pressure monitoring has proved to be an excellent way of detecting so-called white-coat hypertension, which is present in about 20% of subjects with elevated office blood pressures. In these subjects, it may help to avoid unnecessary drug treatment. In addition, ambulatory blood pressure monitoring is a particularly important technique for clinical trials on the antihypertensive effect of single drugs or combined drug regimens. It has been shown that 24-h mean blood pressure is more reproducible than conventional blood pressure values, so that the number of patients required for antihypertensive drug trials may be considerably reduced.

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**Keywords:** Auscultation, oscillometry, ambulatory monitoring, blood pressure, monitoring equipment.

### Introduction

This document was prepared following discussions by working groups on the papers presented at the meeting, a selection of which is published in these Proceedings. Summaries of the working group sessions were discussed

in a plenary session and accepted as a consensus by the participants (see page S1). The document was then further refined for publication, with specific contributions from A. Coats, J. Conway, A. Distler, E. O'Brien, G. Mancia, W. Meyer-Sabellek, T. Pickering, J. Staessen and T. Strasser.

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## Methodology and devices

Three different methods of 24-h blood pressure monitoring are available (Table 1). (1) Direct intra-arterial ambulatory blood pressure measurements (via catheterization of the brachial or the radial artery) allow a beat-to-beat analysis. However, because the method is invasive it can only be applied after careful training and experience. It is mainly useful for scientific work. (2) Non-invasive intermittent ambulatory blood pressure monitoring by means of a cuff around the upper arm using auscultatory or oscillometric methods is available from portable fully automatic devices [1]. (3) Indirect continuous ambulatory blood pressure monitoring using different methodological approaches (e.g. the finger-volume clamp technique) is still under investigation.

Discussion of the comparison between direct and indirect measurement was inconclusive, some groups maintaining that there is a clear difference between the readings given by the two methods while others did not agree.

**Table 1.** Methods of 24-h blood pressure monitoring.

Method	Technique
Direct continuous	Intra-arterial catheter
Non-invasive intermittent	Auscultation by microphone(s) in an occlusive arm cuff
	Oscillometry by amplitude detection in an adjusted arm cuff
	Plethysmography in a finger cuff
Indirect continuous	Plethysmography and photoelectrical evaluation by volume clamp (Peñáz) in a finger cuff

The most widely used method today is non-invasive intermittent ambulatory blood pressure monitoring. The following factors must be taken into consideration in selecting an ambulatory blood pressure monitoring system: (1) accuracy and reliability (see discussion on validation below); (2) patient acceptability (insufficient work has been done at present on a standard by which this factor can be assessed); (3) computer compatibility; and (4) cost.

There are two national validation protocols, those of the American Association for the Advancement of Medical Instrumentation (AAMI) [2] and of the British Hypertension Society (BHS) [3], that address the accuracy of ambulatory blood pressure monitoring systems. There are a number of national standards, such as that of the German Physikalisch-Technische Bundesanstalt (PTB), which are concerned with mechanical performance. Validation requirements should be standardized as far as practicable, and the more stringent requirements of the BHS and the AAMI should be adopted by other national bodies. To date, two systems have satisfied the AAMI requirements for both systolic and diastolic pressures, the SpaceLabs 90202 and the Medilog [4]. Other systems are under investigation by the BHS protocol and the results are expected shortly [4]. All these systems, however, require that the patient remain immobile while the measurement

is being taken, and accurate non-invasive blood pressure measurements may be difficult to obtain under ambulatory conditions [5-7].

Automated blood pressure measurements can be programmed at preset intervals (2-60 min) and the data can be stored in a solid-state memory.

ECG gating requiring three electrodes on the chest is optional, and helps to differentiate Korotkoff sounds from background noises, but is not generally well accepted by patients. Auscultatory inaccuracy in patients with dysrhythmias (e.g. atrial fibrillation) remains a problem. Weight and pump noise in auscultatory and oscillometric systems should be minimized to reduce discomfort, alertness and disturbance to sleep. With the devices now available (weight < 500 g, pump noise < 25 dB) no alerting reactions to intermittent cuff inflation during non-invasive ambulatory blood pressure monitoring have been reported [8]. Although sleep disturbances are likely to occur in some patients [9], the monitoring can be undertaken without affecting the normal nocturnal blood pressure fall and bradycardia [10].

Ambulatory blood pressure monitoring systems should be validated both before and after use [4-6]. The validation can be carried out by comparing results from the ambulatory system with conventional measurements taken simultaneously from the same arm following connection of the system with a mercury column [3]. Differences not greater than  $\pm 5$  mmHg for both systolic and diastolic pressure calculated from a minimum of three readings taken under standardized conditions (e.g. sitting) at 5-10 min intervals can be regarded as acceptable. All parts of the system should be checked, with special attention to the batteries. Usually, the energy provided by commercially available, rechargeable batteries is reliable. Nevertheless, the batteries comprise up to 50% of the weight of a portable monitor, and this is an area where improvement is needed.

The cost of the hardware (monitor, interface solid-state memory system, etc.) is considerable (US\$7000-10 000) and the need for a personal computer with floppy and hard disks make it even greater. It is hoped that more widespread use of non-invasive ambulatory blood pressure monitoring will lead to a reduction in the cost. Telephone modem for centralized decoding and evaluation might reduce the hardware cost considerably. However, the present cost must be balanced against the benefits obtained. The most significant benefit is likely to be obtained in a reduction of treatment costs by avoiding overtreatment, especially in patients diagnosed as white coat hypertensives.

## Statistical analysis

Analysis of a 24-h blood pressure recording can be performed in many different ways, the aim being to provide information on 24-h average blood pressure values and day and night blood pressure profiles. Standardization of data analysis has obvious advantages in allowing inter-

study comparisons. Therefore the following criteria are suggested.

- (1) Divide the 24-h period into day and night sub-periods, the daytime running for  $15 \pm 2$  h (7.00 a.m. to 10.00 p.m.) and the night-time for  $9 \pm 2$  h (10.00 p.m. to 7.00 a.m.).
- (2) The intervals between non-invasive measurements should be no longer than 15–30 min for the daytime and 20–30 min for the night-time. Intervals longer than 30 min should not be used because they prevent accurate assessment of 24-h mean values [11]. A protocol of daily activities (e.g. time at work, meals, sleeping time) should be completed.
- (3) Methods of analysis are under discussion [12]. Data analysis should provide the total number of readings and the number of missing and erroneous readings; the arithmetic mean and median for daytime, night-time and 24-h measurements of systolic, diastolic and mean arterial pressures and the heart rate.
- (4) For research and for the assessment of patients, the following options have been discussed. The 24-h blood pressure standard deviation may be a useful measure of blood pressure variability, particularly if measuring intervals of less than 15 min are adopted [11]. Other methods of evaluating blood pressure variability (e.g. day–night blood pressure difference, frequency of blood pressure peaks, etc.) are under investigation.

Non-invasive ambulatory blood pressure monitoring data are often collected at somewhat irregular intervals due to rejection by the device of erroneous readings. The blood pressure signal may often be unstable due to spikes (possibly event-triggered) and artifacts of the device (<5%). To evaluate the 24-h blood pressure profile, therefore, a 'smoothing procedure' is recommended [13]. This would also solve the problem of time-weighting, which arises when the night-time blood pressure is sampled less frequently to avoid disturbing the subject's sleep.

The cosinor approach may be too rigid to give an appropriate summary of the data, because it assumes an exactly symmetrical blood pressure behaviour between high and low pressure periods and the 24-h period is inflexibly divided into set periods. The spline models are more flexible but also more complex computationally [12,13].

Blood pressure measurements are only approximately, not exactly, normally distributed. Therefore, many researchers recommend the use of non-parametric procedures. These methods are more robust and reduce the need for editing. Non-automatic editing processes should be employed with caution because they can lead to subjective manipulation of the original data.

## Normal values

In most subjects, ambulatory blood pressure means are lower than office blood pressures and the difference appears to increase with increasing office blood pressure levels. Normal ambulatory blood pressure levels, however, have been studied only in limited groups of subjects, who were often preselected by normal blood pressure on conventional measurements. Therefore, normal 24-h blood pressure values cannot be conclusively defined at present.

A meta-analysis of studies on non-invasive ambulatory blood pressure monitoring in healthy and apparently normotensive subjects has recently been performed (Fig. 1) [14]. The results suggest that a daytime mean blood pressure of  $\geq 135/85$  mmHg may represent a hypertensive condition (the full 24-h mean may be lower). This may be taken as the provisional cutoff levels between a normal and high daytime blood pressure, pending the results of studies from non-selected general populations including untreated hypertensives [7].

## Clinical indications

The clinical value of ambulatory blood pressure monitoring has not yet been clearly established. There is a need for guidelines for the diagnosis and treatment of hypertension based on ambulatory blood pressure measurement, similar to those for clinic blood pressure measurements.

The data available so far suggest that non-invasive ambulatory blood pressure measurements may help in identifying white coat hypertension [15,16]. It may also be useful in the following conditions.

### Essential hypertension

If there is no target-organ damage and blood pressure is in the mild to moderate hypertensive range, a mean 24-h blood pressure similar to the office blood pressure may strengthen the decision to treat. Ambulatory blood pressure monitoring may have less value for the diagnosis of hypertension when target-organ damage is present and/or office blood pressure is markedly or persistently elevated (e.g. diastolic pressure  $\geq 110$  mmHg) [15], because under these conditions treatment of hypertension is mandatory.

### Secondary hypertension

In some types of secondary hypertension there may be little or no reduction in nocturnal blood pressure levels and therefore 24-h non-invasive ambulatory blood pressure monitoring may offer additional diagnostic information, e.g. for pre-eclampsia and hypertension associated with Cushing's disease [17]. Ambulatory monitoring can also be useful in the diagnosis of pheochromocytoma [18], particularly when short hypertensive crises do not allow conventional measurements to be taken in time and do not show whether plasma catecholamines are clearly increased.

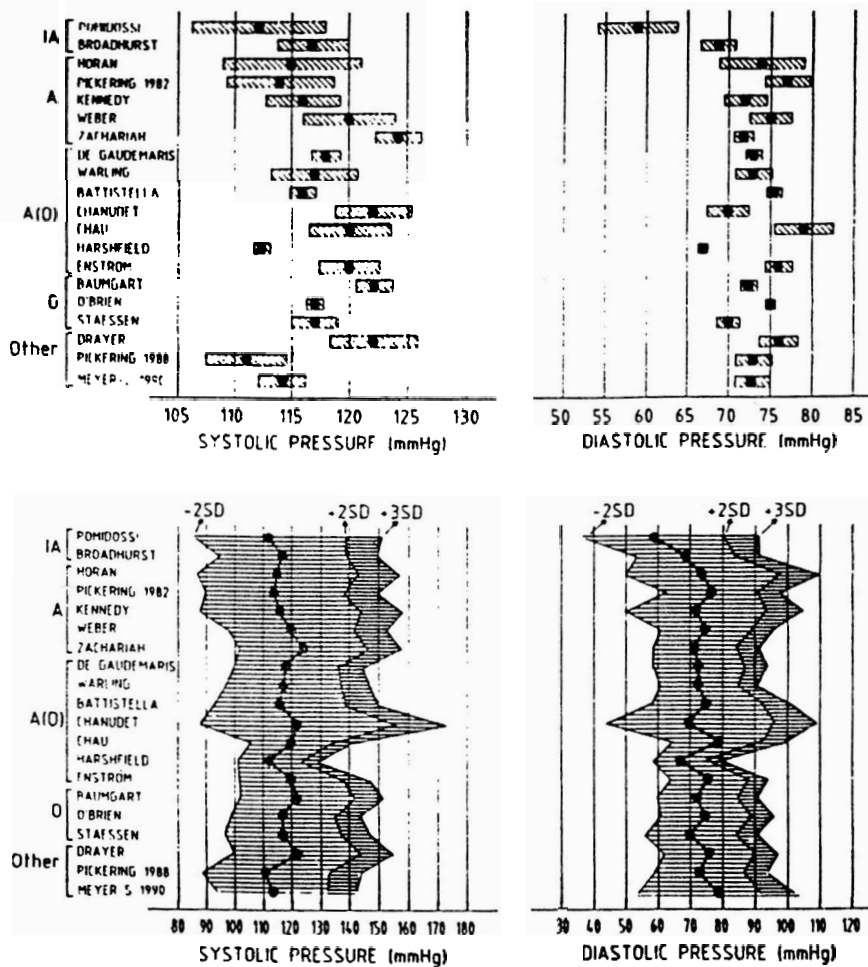


Fig. 1. Normal 24-h ambulatory blood pressure measurement values obtained from published studies, showing (a) mean and 95% confidence intervals for each study and (b) mean + 2 and mean + 3 s.d. IA, intra-arterial; A, auscultatory; A(O), auscultatory with oscillometric back-up; O, oscillometric. From [14].

**Evaluation of treatment**

Non-invasive ambulatory blood pressure measurement can be useful in investigating patients whose office blood pressure does not respond to treatment. It is still not clear which level of ambulatory blood pressure should be the treatment goal. Treated hypertensive patients who show much lower 24-h than office values may be considered basically normotensive; the lack of response to treatment may be more apparent than real and these patients may be overtreated if the treatment decision is based only on the office blood pressure [19].

Ambulatory measurement is a particularly important technique for clinical trials on the antihypertensive effect of single drugs or combined drug regimens [20,21]. It avoids placebo effects [22]. It can show whether blood pressure is reduced during normal daily activity and whether the effect persists over the entire period between doses. Further, 24-h mean blood pressure values are more reproducible than conventional blood pressure values so that the number of patients required for antihypertensive drug trials may be considerably reduced [23,24].

**Prognostic importance**

The ultimate test of the clinical usefulness of non-invasive ambulatory blood pressure monitoring is the degree to which it can assess the risk of cardiovascular morbidity in comparison with conventional blood pressure measurements [25-27]. There are theoretical reasons for supposing that larger numbers of readings taken in more natural circumstances may improve this assessment. Furthermore, there is agreement from a large number of studies that 24-h or daytime mean blood pressure values can be more closely correlated than conventional blood pressure values with the target-organ damage associated with hypertension [28,29]. This has been observed for echocardiographically assessed left ventricular hypertrophy [30], which has the dual advantages of being the most sensitive measure of target-organ damage and of being an important and independent predictor of cardiovascular morbidity and mortality [26,30,31]. It has also been observed for other indices of hypertensive related complications such as microalbuminuria [32], pulse wave velocity (an index of arterial stiffness) and score derived from a history of cardiovascular complications, ECG, chest X-ray and fundoscopic changes ori

inally proposed by Sokolow *et al* [33]. It is not clear whether any particular value or time segment of the 24 h is paramount in predicting the consequences of hypertension. In some studies, left ventricular hypertrophy was greater in those hypertensives with lesser blood pressure falls at night or those who had higher blood pressures at work [26,34]. Further, the standard deviation of 24-h blood pressure has been correlated with target-organ damage, suggesting that not only mean ambulatory blood pressure but also blood pressure variability may be important [7].

While these studies suggest that ambulatory blood pressure monitoring has a prognostic value, it is difficult to draw causal inferences from cross-sectional studies and so far there is only limited evidence on the relationship between ambulatory blood pressure values and the incidence of cardiovascular morbidity and mortality. One study [27] contained only preliminary results from a larger database which is still being compiled. In another study [29] ambulatory blood pressure was shown to be additional to office blood pressure in predicting cardiovascular morbidity and mortality. However, the ambulatory blood pressure was recorded only at entry to the study and the effect of treatment on blood pressure and prognosis was not reported. Further, only daytime values were recorded.

The evidence that ambulatory blood pressure monitoring can improve the assessment of prognosis for hypertension is thus encouraging but incomplete. A prospective controlled study is required to address the question of whether ambulatory blood pressure is a significantly better predictor of cardiovascular morbid and fatal events than office blood pressure and/or adds to the prediction offered by office blood pressure. While it may be impractical to take cardiovascular events as the outcome variable, useful information may be obtained by assessing the development of intermediate markers of cardiovascular disease such as left ventricular hypertrophy. Such a study may be further complicated by the potentially confounding effect of antihypertensive treatment. For the time being, therefore, office blood pressure should be taken as the primary indicator of prognosis.

### Future directions

Some of the research directions required for the future are outlined below.

Studies are required to describe the population distribution of ambulatory blood pressure parameters including daytime, night-time and 24-h values, the day-night difference, blood pressure variability and the clinic-ambulatory difference. This distribution is needed for all age-sex strata. A prospective epidemiological study is required to relate ambulatory blood pressure parameters to cardiovascular morbidity and mortality. The hypothesis that treatment is clearly indicated above certain levels of ambulatory blood pressure needs to be tested.

There is little or no information on normal values of ambulatory blood pressure in certain populations [34], e.g. pediatrics, the elderly, pregnant women, different cultural groups and different racial groups. Finally, longitudinal studies are required to determine the independent prognostic significance of blood pressure variability, the alerting response, night-time blood pressure levels and the day-night difference in comparison with mean daytime blood pressure.

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