

# Review Article

## Ambulatory Blood Pressure Monitoring

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### Abstract

Blood pressure measurements in the office are strongly associated with cardiovascular disease morbidity and mortality, but do not correlate well with 24 h blood pressure values. Ambulatory blood pressure monitoring (ABPM) is a powerful tool for investigating the true blood pressure burden in individual patients and currently accepted as the gold standard for diagnosing hypertension. ABPM can improve cardiovascular risk stratification for individual patients and evaluate for other abnormal blood pressure phenotypes. Here, we review the use of APBM, summarize data suggesting the superior predictive value of ABPM for cardiovascular disease, and practical applications for its clinical use.

**Key words:** Ambulatory blood pressure monitoring, hypertension, cardiovascular disease, masked hypertension

### Introduction

Accurate measurement of blood pressure is crucial for identifying and treating hypertension. Hypertension identified in a clinical setting is strongly associated with cardiovascular disease morbidity and mortality.<sup>[1]</sup> However, blood pressure fluctuates during the day, and office blood pressure readings do not correlate well with 24 h blood pressure values.<sup>[2]</sup> Therefore, out of office blood pressure measurement has been used to better characterize the true burden of hypertension and predict cardiovascular risk in individual patients. Ambulatory blood pressure monitoring (ABPM) captures out of office blood pressure values and more accurately reflects the total blood pressure load and variability in an individual patient. Here, we will review the predictive value and role of ABPM in clinical practice.

### Protocol for ABPM

Ambulatory blood pressure monitors are connected to a sphygmomanometer cuff on the upper arm and usually attached to a belt or pouch. Readings are measured every 15–30 min throughout the day and night and are typically blinded to the patient. Measurements are automatically downloaded onto a

computer for processing while the patient monitors and logs their daily activities. There is no standard approach to determine an adequate or valid 24 h ABPM session. Guidelines suggest that greater than 70–80% of planned readings<sup>[3]</sup> or at least 10 readings during the daytime and at least 5 during the nighttime<sup>[4]</sup> are required.

Validation procedures for ABPM devices are available from several organizations<sup>[5,6]</sup> and an updated list of monitors validated for clinical use is readily found online ([www.dablededucational.org](http://www.dablededucational.org)).

### Blood Pressure Treatment Thresholds

ABPM uses different thresholds for defining hypertension than office-based blood pressure measurements. Thresholds have been suggested based on data from European, Australian, Asian, and African-American populations.<sup>[7–10]</sup> These data have been summarized in the 2017 ACC/AHA guideline for blood pressure management, a summative statement on the prevention, identifying, evaluation, and treatment of high blood pressure in adults. In general, a clinic blood pressure of 140/90 mmHg generally corresponds to blood pressure at home of 135/85, 24 h ABP of 130/80 mmHg, daytime ABP of 135/85 mmHg, and nighttime ABP of 120/70 mmHg.<sup>[11]</sup> The precise relationships between office readings, home BP readings, and ABP readings

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have not been classified in all populations, and therefore, these thresholds should be used as a general guide in individual patients.

### Association between Ambulatory Blood Pressure and Subclinical and Clinical Cardiovascular Disease

Several components of the ABP, including the 24 h mean ABP, daytime ABP, and nighttime ABP, have been shown to be superior to office blood pressure readings for predicting end-organ dysfunction.<sup>[12]</sup> Several studies have demonstrated stronger cross-sectional and longitudinal associations between ABP and left ventricular hypertrophy and dysfunction, proteinuria, the progression of CKD, atherosclerotic plaques, and cerebral infarcts or white matter lesions on MRI<sup>[13-16]</sup> than with OBP.

In a cross-sectional study of 108 patients, the 24 h mean BP predicted hypertensive target organ damage beyond casual BP measurements.<sup>[15]</sup> In a study of 74 hypertensive individuals, the 24 h mean ABP was significantly associated with the left ventricular mass and wall thickness even when accounting for clinic BP measurements.<sup>[17]</sup> In a study of 75 individuals with type 1 diabetes, an increase in sleep SBP was associated with incident microalbuminuria, whereas office measurements did not correlate with incident microalbuminuria.<sup>[18]</sup>

Considerable evidence exists suggesting that ABPM more strongly predicts cardiovascular disease than office blood pressure (OBP) measurements.<sup>[19]</sup> A landmark study by Perloff *et al.* first demonstrated that hypertensive patients with higher ABP had a greater cumulative frequency of fatal and non-fatal cardiovascular events than those with lower ABP.<sup>[20]</sup> In 1076 patients with essential hypertension with an average follow-up time of 5.1 years, there were 228 (21.2%) total clinical cardiovascular events. Patients with a mean ABP  $\geq$  10/6 mmHg higher than predicted based on the office BP had a statistically significantly higher cumulative incidence of a first clinical cardiovascular event than those with an ABP that was  $\geq$  10/6 mmHg lower than the office BP predicted.

Subsequent studies have shown the superiority of ABPM at predicting cardiovascular events<sup>[21-23]</sup> as well as cardiovascular mortality,<sup>[22,24,25]</sup> even after adjustment for conventional risk factors, most of which account for OBP measurements. Among patients with treated hypertension, ABP is superior to OBP for stratifying cardiovascular risk and predicting incident cardiovascular events.<sup>[26-28]</sup> In a study of 1963 patients with treated hypertension and median follow-up of 5 years, the baseline mean 24 h SBP and DBP independently predicted new cardiovascular events, even when adjusting for office BP.<sup>[26]</sup> The adjusted relative risk of a new cardiovascular event was 1.34 (95% CI 1.07–1.57) for 24 h ambulatory SBP and 1.21 (95% CI 1.01–1.46) for 24 h ambulatory DBP.

### Hypertension Phenotypes Defined by OBP and ABP Measurements

Four phenotypes of blood pressure can be defined by characterizing both OBP and ABP within individual patients: Normotension

(normal clinic and ABP measurements), hypertension (elevated clinic and ABP measurements), white coat hypertension (elevated clinic and normal ABP measurements), and masked hypertension (normal clinic and elevated ABP measurements).<sup>[11]</sup> ABPM can also reveal abnormal circadian variation of blood pressure. Blood pressure normally follows a diurnal pattern of variation, falling to its lowest levels during the first few hours of sleep (dipping) and rising to its highest levels early in the morning on awakening.<sup>[29]</sup> The normal nocturnal fall in BP is  $>$  10%, but some persons have a blunted fall or an increase in BP with sleep, termed non-dipping and reverse dipping, respectively. The clinical significance of these phenotypes is described below.

#### Masked hypertension

An estimated 15–30% of the general population have masked hypertension.<sup>[30]</sup> Estimates vary by geographic region,<sup>[31]</sup> the ABP periods used to define hypertension status,<sup>[32]</sup> demographics,<sup>[33]</sup> and comorbidities.<sup>[34,35]</sup> Specifically, high rates of masked hypertension have been demonstrated in African Americans<sup>[33]</sup> and in persons with chronic kidney disease.<sup>[34,35]</sup> Masked hypertension has been increasingly classified as a high-risk phenotype, strongly linked with an increased risk of hypertensive organ damage including increased left ventricular mass,<sup>[14]</sup> arterial stiffness and carotid intima-media thickness,<sup>[36]</sup> and albuminuria<sup>[37]</sup> as well as cardiovascular events.<sup>[38,39]</sup>

#### White coat hypertension

White coat hypertension is suspected in persons with elevated clinic blood pressures but with normal home blood pressure readings and the absence of target organ dysfunction. It is generally accepted that persons with white coat hypertension have a similar risk of incident cardiovascular events compared to those with normotension, as demonstrated by a large meta-analysis (Fagard and Cornelissen, 2007). However, white coat hypertension may be associated with prevalent albuminuria<sup>[37]</sup> and an increased risk of future stroke.<sup>[40]</sup>

#### Abnormal dipping

Abnormal nocturnal dipping can occur in both normotensive and hypertensive persons. In particular, reverse dipping is documented more frequently in persons with diagnosed hypertension, kidney disease, type 2 diabetes mellitus, and obstructive sleep apnea.<sup>[41]</sup> Both blunted and reverse dipping patterns, even when accounting for the office and daytime ABP, have been shown to be associated with a higher risk of coronary events, stroke, cardiovascular events, and all-cause mortality.<sup>[42,43]</sup> Reverse dipping has been linked to higher left ventricular mass in African Americans.<sup>[44]</sup> Abnormal dipping has also been associated with glomerular filtration rate decline<sup>[45]</sup> and kidney-associated death in patients with chronic kidney disease.<sup>[46]</sup>

### Evaluating Response to Treatment

Few studies have specifically evaluated the use of ABPM to guide treatment decisions and response to treatment in hypertension.

Staessen *et al.* showed that fewer antihypertensive drugs are prescribed when decisions are based on ABP rather than OBP measurements.<sup>[47]</sup> Whether treatment decisions based on ABP are superior to OBP in outcomes remain to be determined. In one study of 206 individuals with hypertension and left ventricular hypertrophy (LVH), there was a greater association between regression of LVH and a treatment-induced decline in ABP than with changes in OBP.<sup>[48]</sup> Nighttime dosing of antihypertensives may restore normal dipping, reduce nocturnal hypertension, and reduce cardiovascular events.<sup>[49-52]</sup> ABPM, therefore, would be useful to assess dipping response to therapy.

### Clinical Indications for ABP Monitoring

Practice guidelines and position papers including those from the European Society of Hypertension,<sup>[3]</sup> the American College of Cardiology/American Heart Association,<sup>[11]</sup> and the United States Preventive Services Task Force (USPSTF)<sup>[53]</sup> describe the recommended clinical use and applications of ABPM. The USPSTF, citing the consistent association between elevated ambulatory systolic BP and cardiovascular events independent of OBP, specifically recommends ABPM as the gold standard for confirming the diagnosis of hypertension.<sup>[53]</sup> However, adhering to this recommendation may not be feasible given the cost, burden, and often limited availability of ABPM devices. In general, ABPM is recommended for excluding white coat hypertension, monitoring the efficacy of antihypertensive treatment in individuals with borderline office BP values, evaluating for masked hypertension in individuals with hypertensive organ damage but normal OBP readings, and evaluation of diurnal patterns of blood pressure.<sup>[54]</sup> ABPM may also be helpful to assess labile blood pressures, hypotension, and elevated BP readings in the elderly and in pregnancy.<sup>[54]</sup>

### Conclusions

ABP monitoring is a powerful tool for investigating the true blood pressure burden in individual patients. It is widely accepted as the gold standard for the diagnosis of hypertension. It has been well-established that ABP values are better predictors of cardiovascular risk than OBP values. ABPM can assist in ruling out white coat hypertension, identifying masked hypertension, and abnormal diurnal BP patterns. However, the widespread use of ABPM may be limited by burden to patients, cost, and limited availability of monitoring programs. As most of the current treatment guidelines are based on results from large trials using in office BP readings, future studies are needed to understand the utility of ABPM to guide and modify treatment to decrease cardiovascular risks.

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