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Blood Pressure Measurement: Clinic, Home, Ambulatory, and Beyond

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Abstract

Blood pressure has traditionally been measured in the clinic setting using the auscultatory method and a mercury sphygmomanometer. Technological advances have led to improvements in measuring clinic blood pressure and allowed for measuring blood pressures outside the clinic. This review outlines various methods for evaluating blood pressure and the clinical utility of each type of measurement. Home blood pressures and 24 hour ambulatory blood pressures have improved our ability to evaluate risk for target organ damage and hypertension related morbidity and mortality. Measuring home blood pressures may lead to more active participation in health care by patients and has the potential to improve blood pressure control. Ambulatory blood pressure monitoring enables the measuring nighttime blood pressures and diurnal changes, which may be the most accurate predictors of risk associated with elevated blood pressure. Additionally, reducing nighttime blood pressure is feasible and may be an important component of effective antihypertensive therapy. Finally, estimating central aortic pressures and pulse wave velocity are two of the newer methods for assessing blood pressure and hypertension related target organ damage.

Hypertension is an important, modifiable risk factor for cardiovascular events, end-stage renal disease (ESRD), and mortality. A vast body of evidence has documented that office based blood pressure measurements predict risk of adverse outcomes and serve as therapeutic targets in the management of hypertension.¹ The issue of target levels of office blood pressure control in the general population and in patients with chronic kidney disease has recently been extensively discussed,^{2,3} and will therefore not be addressed in this paper, which focuses on measuring blood pressure. While clinic based blood pressures have long

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been used in clinical trials and the management of patients with hypertension, there has been increasing interest in blood pressures measured outside the office setting, and there have been advances in technology enabling more sophisticated measures of vascular structure and function.⁴ It has been suggested that the current reliance on clinic blood pressure alone might result in substantial overdiagnosis of hypertension; ambulatory monitoring might allow for more appropriate targeting of patients most likely to benefit from lifelong drug treatment.⁵ In fact, some recent guidelines mandate confirmation of elevated office blood pressures by measuring blood pressure at home or by 24 hour ambulatory blood pressure monitoring (ABPM) to make a diagnosis of hypertension.⁵⁻⁷ This area is of particular interest to nephrologists, given the high prevalence of hypertension in patients with chronic kidney disease, and the critical role of blood pressure control in slowing decline in kidney function and reducing risk of cardiovascular disease.

This review summarizes various methods of measuring blood pressure and evaluates recent evidence supporting the use of newer blood pressure measurement techniques with a focus on the patient with chronic kidney disease. We discuss technological advances that improve blood pressure measurement in the office setting, considerations in determining blood pressure at home, issues related to ambulatory blood pressure monitoring, and, briefly, the potential predictive value of central aortic blood pressure measurements.

Office blood pressure measurement

Accurate office blood pressure measurement remains crucial in the diagnosis and management of hypertension. The American Heart Association guidelines for blood pressure measurement emphasize trained observers, correct patient position, a period of quiet rest, use of an appropriately sized cuff, and minimization of extraneous factors that influence blood pressure such as smoking and caffeine intake prior to blood pressure measurement.⁸ Given the inherent variability in blood pressure, standardization of the procedure is very important in obtaining valid readings; unfortunately, these procedures are often not implemented in busy clinical practice settings.⁹ Blood pressures measured under routine conditions may be significantly higher (12.4 mmHg systolic and 6.0 mmHg diastolic; $P < .0001$ for both) than readings taken following recommended guidelines.¹⁰ It is also important to obtain the average of several readings, rather than use a single reading, both for clinical management and for evaluating the quality of hypertension management.¹¹ Falsely high clinic readings can prompt inappropriate addition or escalation of antihypertensive drug therapy and increase risk for adverse drug effects. The current classification of hypertension based on office blood pressure readings is summarized in table 1.^{12,13}

Blood pressure measurement in the clinic has relied primarily upon the use of the auscultatory method with mercury, aneroid, or hybrid sphygmomanometers. While still accepted as the 'gold standard' for blood pressure measurement, mercury sphygmomanometers are gradually being phased out primarily due to environmental concerns.¹⁴ Aneroid monitors are commonly used; in order to maintain accuracy of these devices a yearly calibration program with a ± 2 mmHg standard should be followed. Wall mounted devices require more frequent calibration due to susceptibility to damage.¹⁵ Hybrid

BP measurement devices avoid the problem of mercury toxicity and give the choice of auscultatory or automated measurement.¹⁶⁻¹⁹

Automated devices that work on the principle of measuring the oscillation in the arterial wall during deflation of the cuff have been validated in patients with essential hypertension and in those with chronic kidney disease.^{12,20} Several recent devices offer improved features (as discussed below) and have increased in popularity. A key advantage of these newer monitors is that they can be programmed to start measuring blood pressure after a set time following placement of the cuff (usually five minutes), thus enforcing the period of rest recommended by national guidelines. The automated monitor can take several readings and provide the average value while also eliminating the observer's digit preference. Importantly, the observer can leave the room during measurement to minimize the white coat effect.²¹ Readings taken using the BpTRU automated blood pressure monitor (VSM MedTech Ltd) have been reported to be, on average, about 10 mmHg less than standard in-office blood pressures and better match ABPM-determined average daytime blood pressure.²² These devices overcome many of the disadvantages of typical office BP measurement (i.e., digit preference, observer bias, white-coat effect) without losing the convenience of in-office monitoring.²³⁻²⁶

Traditionally, mean blood pressures have been used to evaluate risk for hypertension related morbidity and mortality. Recent data demonstrate that variability in systolic blood pressure across several different visits is a strong predictor of stroke, independent of mean systolic blood pressure. Patients with the most variability in blood pressure (as measured by standard deviation) over seven visits had an approximately six fold higher risk of stroke compared to those with the lowest variability.²⁷ While intriguing, further research is needed to evaluate the role of blood pressure variability as a risk factor and a potential therapeutic target in hypertensive patients.

Home blood pressure monitoring

Overview

Home blood pressure monitoring is an attractive option in the management of hypertension because it provides an inexpensive and convenient method to measure blood pressure in an environment familiar to the patient.²⁸ The reproducibility of home blood pressure monitoring is comparable, or even better, than traditional office based blood pressure measurements and it overcomes some biases in office based readings such as digit preference and observer bias.²⁹⁻³⁴ Home blood pressure monitoring makes estimating the duration of antihypertensive drug efficacy possible³⁵⁻³⁷ and may be particularly helpful in patients with diabetes, chronic kidney disease, non-adherence, suspected white coat effect, and masked hypertension, as discussed below.³⁸ It is also helpful in children and the elderly, in whom the white coat effect is often prominent^{39,40} and to improve monitoring of blood pressure during pregnancy.³⁹ Several analyses have shown that regular use of home blood pressure monitoring lowers health care costs associated with treatment of hypertension and its complications.^{30,41-46}

Measurement of home blood pressure

It is important to provide instructions and train patients to standardize the process of measuring blood pressure at home.^{47,48} The usual precautions with regard to a rest period prior to measurement, appropriate patient position and cuff size, and avoidance of factors that can influence blood pressure (such as caffeine and smoking) should be implemented while measuring blood pressure at home.³⁹ In order to minimize anxiety over home blood pressure readings, providers should educate patients that home blood pressure measurement is one component of the overall hypertension management plan. Patients should use automated brachial blood pressure monitors that have been validated^{30,35,49} and calibrated annually against standardized clinic measurements.^{39,50} Use of the arm cuff is preferred compared to wrist and finger monitors.^{30,35} Home blood pressure should be measured twice daily for a 3-7 day period; some investigators do not use the values on the first day of monitoring to allow patients to acclimate to the process.^{37-39,51} Every measurement should be documented along with the pulse rate, time, and date; devices with an attached printer or an integrated memory can help avoid selection bias.⁵² The reliability of readings may be decreased by arrhythmias and frequent ectopic beats.³⁰ Adherence to home blood pressure measurement and the accuracy of home blood pressure measurements have not been well studied.

Home blood pressures are generally lower than blood pressures measured in the clinic with larger differences in measurements in men than women, with increasing age, and in untreated patients compared to those on antihypertensives.³⁷ The JNC 7, European, and Canadian Hypertension guidelines recommend that home blood pressure values greater than 135/85 mmHg be defined as hypertensive (see Table 1).^{12,13,53} However, some experts have proposed that a home blood pressure of 130/80 mmHg should be targeted in high risk patients because the incidence of cardiovascular complications is lower at these levels.^{39,54}

Home blood pressure and prognosis

Home blood pressure readings correlate better with ambulatory blood pressure than office blood pressure readings (home readings 0.75; physician reading $r=0.46$; nurse readings 0.48-0.60; self measurement in clinic 0.63-0.73).^{55,56} More importantly, home blood pressure measurements predict hypertensive target organ damage such as left ventricular hypertrophy and atherosclerosis better than traditional office based readings.⁵⁷⁻⁶⁰ In fact, some data argue that measuring blood pressure at home might outperform ABPM in predicting hypertensive target organ damage^{58,61-63}

Several studies (summarized in Table 2) have evaluated the prognostic significance of home blood pressure monitoring and demonstrated that home blood pressure may be a superior prognostic indicator of cardiovascular morbidity and mortality than office blood pressure.^{41,64-66} In the recent Finn-Home study, in models including both home and office blood pressures, only home blood pressure (HR, 1.22; 95% CI, 1.09 to 1.37), but not office BP (HR, 1.01; 95% CI, 0.92 to 1.12), was predictive of cardiovascular events.⁶⁶ Total mortality was also significantly associated with only systolic home blood pressure (HR, 1.11; 95% CI, 1.01 to 1.23).⁶⁶ In patients with kidney disease, limited data demonstrate that home blood pressure (HR, 1.74; 95% CI, 1.04 to 2.93) is a stronger predictor of end stage

renal disease or death compared to office blood pressure.⁶⁷ Although not consistent across all studies,⁶⁸ there is clear and convincing evidence that blood pressures measured in the home are better predictors of cardiovascular risk in patients with hypertension than clinic based blood pressures.

Home blood pressure monitoring in the management of hypertension

Beyond its value as a prognostic marker, home blood pressure monitoring may contribute in many ways to the management of hypertensive patients. The availability of home blood pressure measurements may overcome therapeutic inertia, triggering the physician to treat hypertension more quickly or aggressively than in the absence of this information.⁶⁹ It is also reasonable to expect that active participation of patients in their health care may improve therapeutic compliance.^{42,64,70} McManus et al assessed whether self-monitoring using automated devices could improve blood pressure control compared to usual care.⁷¹ Patients with uncontrolled hypertension (n=441) were randomized to usual care or an “intervention group” that received treatment targets and was given access to electronic blood pressure machines in the clinic. The intervention resulted in a 4.3 mmHg greater reduction in systolic blood pressure at 6 months but there was no significant difference after one year.⁷¹ Similar results were noted in Treatment of Hypertension Based on Home or Office Blood Pressure (THOP), another important study in this field.⁷² Adjusting antihypertensive treatment in response to blood pressure measured at home instead of in the office achieved marginally lower medical costs and less intensive drug treatment, but also reduced long-term blood pressure control.⁷² A meta-analysis of 18 randomized controlled trials revealed lower blood pressure in patients who had home blood pressure monitoring compared to patients monitored under standard clinic conditions (standardized mean difference, 4.2 (95% CI 1.5-6.9) and 2.4 (95% CI 1.2-3.5) mmHg for systolic and diastolic blood pressure, respectively).⁷³ Home blood pressure monitoring was associated with more patients reaching goal blood pressure. However, there was significant heterogeneity across studies suggesting that the approach to implementation is important and that large-scale, randomized, controlled studies are needed to evaluate the efficacy of home blood pressure monitoring in patients with hypertension.^{69,70,74}

Self-titration of antihypertensive drug therapy based on home blood pressure readings is also an interesting intervention. In a study in which patients self-titrated antihypertensive drugs based on home blood pressures (which were also telemonitored), the intervention group had lower blood pressure than usual care (difference between groups 5.4 mmHg; P = 0.0004).⁷⁵ Thus, home blood pressure monitoring in combination with telemonitoring and self-management may be an effective new approach to control hypertension.⁷⁵⁻⁷⁷ Similarly, hypertension management programs based in the work place have proven effective in lowering blood pressure and bringing a greater proportion of patients in line with the target blood pressure.^{78,79} However, the predictive value of work based blood pressures is unknown.

In summary, when used by trained patients using validated monitors, home blood pressure monitoring can provide important prognostic information, and facilitate the management of hypertension. With mobile technology and increasing capability to transmit such

information over the internet, it is likely that home blood pressure monitoring will play a larger part in the clinical management of hypertensive patients.

Ambulatory Blood Pressure Monitoring (ABPM)

Ambulatory blood pressure monitoring has been studied extensively in many different patient populations, and is a valuable tool in the management of the hypertensive patient. ABPM measures daytime and nighttime blood pressure, and provides an assessment of diurnal blood pressure changes, which, as outlined below, are important predictors of hypertension related morbidity and mortality (see Figure 1).⁵³

Currently, evaluating for white-coat hypertension (elevated clinic blood pressure with normal blood pressure outside the medical environment) is the only indication for ABPM that Medicare will reimburse. Other indications include evaluation of autonomic neuropathy, syncope, hypotension, resistant hypertension, diurnal blood pressure variation, and effect of antihypertensive medications over the entire 24 hour period.^{20,53,80,81} Guideline recommended threshold values for ABPM are shown in Table 1.^{20,53,80}

Conducting ABPM requires the proper equipment and careful training of clinic staff to ensure accuracy of the procedure. Ambulatory blood pressure monitors should be validated according to protocols established by the European Society of Hypertension and the American Association for Medical Instrumentation.⁸² The monitor should be fitted after the patient relaxes quietly for at least 5 minutes.^{20,53,80} Blood pressure is then measured in both arms and an appropriately sized cuff placed on the non-dominant arm if the difference in systolic blood pressure is less than 10mmHg (the arm with the greater pressure is used if the difference is ≥ 10 mmHg).⁵³ Additionally, clinic staff should explain the details of the procedure including the frequency of measurement (typically every 15 to 30 minutes during the day and every 30 minutes at night) and instruct patients to ensure the monitor stays attached, to continue to conduct their normal daily activities, and to keep the monitored arm steady and level with the heart during each reading for the entire 24 hour period.^{53,80} A diary of sleep and wake times is often used to define day and night periods as well as the timing of antihypertensive administration and any symptoms potentially related to high or low blood pressures.⁵³ Some monitors include an actigraphic device that assesses body movements and that information can be used to define day and night intervals.⁸³ A minimum of 14 readings during the day and 7 readings at night are required for a valid 24 hour ABPM.⁵³

Elevated ambulatory blood pressure is associated with increased risk for cardiovascular disease and all-cause mortality in the general population, hypertensive patients, and patients with resistant hypertension.⁸⁴⁻⁸⁷ This association between ambulatory blood pressure and adverse outcomes is independent of clinic BP (Table 3).^{84,86-88} Diurnal variation in blood pressure has also been extensively studied as a predictor of outcomes.⁸⁹⁻⁹¹ In most individuals, blood pressure decreases during the night; lack of decline in blood pressure at night ("non-dipping") is defined as a night to day blood pressure ratio >0.90 . While the night-day ratio is often dichotomized, the cut-off of 0.90 may be arbitrary and it is preferable to analyze the ratio as a continuous variable.⁹² Among older patients with isolated systolic

hypertension, a 10% increase in the night-day ratio was associated with a 41% increased risk of cardiovascular events.⁸⁹ Whereas multiple studies have evaluated the significance of night-day blood pressure ratios, it is unclear if the dichotomous definition (dipper vs non-dipper) is reproducible in individual patients over time, and the field is moving toward using nocturnal blood pressure rather than dipping status as a predictor of outcome.

A recent meta-analysis including both population based (9,641 patients) and hypertension cohorts (23,856 patients) demonstrated that daytime blood pressure was no longer a significant predictor after adjusting for nighttime blood pressure, except for predicting cardiovascular events in the general population.⁹⁰ On the other hand, even after adjustment for daytime blood pressure, nighttime readings remained a significant predictor of cardiovascular events and all-cause mortality both in the general population and in hypertensive patients.⁹⁰ These results confirmed the findings from IDACO (the International Database on Ambulatory blood pressure monitoring in relation to Cardiovascular Outcomes) in which nighttime blood pressures were more consistent predictors of mortality and cardiovascular events than daytime blood pressures.⁹³ Thus, ABPM provides additional information beyond clinic blood pressure regarding risk for hypertension associated morbidity and mortality. Much of this added benefit stems from the ability to measure nighttime blood pressure.

The importance of ABPM is magnified in patients with CKD because both decreased glomerular filtration rate (GFR) and proteinuria are associated with elevated nighttime blood pressure and non-dipping.⁹⁴⁻⁹⁸ This was well demonstrated in the African American Study of Kidney Disease (AASK), in which patients with seemingly similar office blood pressure readings had markedly different nighttime blood pressure (see Figure 2).⁹⁹ However, few studies have evaluated ABPM's prognostic significance in patients with kidney disease.¹⁰⁰⁻¹⁰² In a study of 277 patients with CKD, ambulatory blood pressure was better than clinic blood pressure at predicting ESRD or death.¹⁰¹ More specifically, elevated nighttime blood pressure was associated with increased risk for all-cause mortality and a composite of ESRD or death even after adjusting for daytime ambulatory blood pressure. Similarly, among 436 Italian CKD patients, ambulatory was superior to clinic blood pressure, while nighttime was superior to daytime blood pressure for predicting renal and cardiovascular events.¹⁰² Additionally, non-dipping was associated with increased risk for both cardiovascular events and renal death.¹⁰² Comparable results have been seen in dialysis patients, in whom elevated nighttime blood pressure and non-dipping are associated with increased risk for cardiovascular events, cardiovascular mortality, and all-cause mortality.¹⁰³⁻¹⁰⁷ So, while there are fewer and smaller studies in patients with CKD, the findings are consistent with non-CKD cohorts and indicate that ambulatory blood pressure is superior to clinic blood pressure for predicting adverse events. Additionally, nighttime blood pressure may have greater predictive ability than daytime blood pressure again reinforcing the benefits of ABPM for evaluating risk associated with hypertension.

ABPM may provide more than just prognostic information. Ambulatory blood pressure and nighttime blood pressure have the potential to be therapeutic targets, given that a number of studies have demonstrated these blood pressures to be modifiable. Over 15 years ago, investigators observed that nighttime dosing of isradipine more effectively lowered

nighttime blood pressure than morning dosing with similar effects seen on 24hr and daytime blood pressure.¹⁰⁸ In a study of non-dipping patients with CKD, shifting at least one antihypertensive medication from the morning to the evening resulted in lower nighttime blood pressure, restoration of normal dipping in 88% of patients, and no change in daytime or 24hr blood pressure.¹⁰⁹ Finally, in the Ambulatory Blood Pressure Monitoring for Prediction of Cardiovascular Events (MAPEC) study, 2,156 subjects were randomized to receive a) all antihypertensives in the morning or b) at least one antihypertensive in the evening.¹¹⁰ After a median follow up of 5.6 years, evening dosing of at least one antihypertensive decreased the risk for major cardiovascular events and all-cause mortality.¹¹⁰ Similar effects were seen in the subgroup of patients with CKD.¹¹¹

White-coat and Masked Hypertension

Categorizing patients by measuring blood pressure both in the clinic and outside the clinic (home blood pressure or ABPM) provides important prognostic information and helps to guide the treatment of patients with hypertension. Patients can be categorized as: 1) true normotension (clinic BP <140/90mmHg and ambulatory daytime blood pressure <135/85mmHg); 2) white-coat hypertension (elevated clinic blood pressure and normal ambulatory blood pressure); 3) masked hypertension (normal clinic blood pressure and elevated ambulatory blood pressure); and 4) sustained hypertension (elevated clinic and ambulatory blood pressure).²⁰ Compared to true normotension, all forms of hypertension are associated with increased risk for hypertensive target organ damage and adverse clinical outcomes, although the risk is higher in patients with masked and sustained hypertension than in patients with white-coat hypertension.¹¹²

White-coat hypertension, present in approximately 5-20% of patients with CKD, is associated with risk factors for and surrogate markers of cardiovascular disease including albuminuria, increased carotid intima-media thickness, increased left ventricular mass, and elevated muscle sympathetic nerve activity.¹¹³⁻¹¹⁸ Patients with white-coat hypertension are at increased risk for developing sustained hypertension; approximately 10 to 20% of patients with normotension and 30 to 45% of patients with white-coat hypertension developed sustained hypertension when followed for 5-10 years.^{112,119,120} Additionally, patients with white-coat hypertension may be at greater risk for cardiovascular events and all-cause mortality.^{121,122} In a large population based cohort, white-coat hypertension was associated with increased risk for both cardiovascular disease and all-cause mortality when defined by either home or ambulatory blood pressures.¹²¹ However, results are not consistent across all studies and recent meta-analyses indicate that patients with white-coat hypertension are not at increased risk for adverse clinical events compared to normotensives.^{59,112,123-125} Patients with CKD and white-coat hypertension have a lower risk for progression to ESRD than those with sustained hypertension.^{101,112,119,120} Therefore, while it is unclear whether white-coat hypertension is associated with increased risk for hard clinical outcomes, it is reasonable to monitor these patients with home blood pressure or ABPM and to treat them appropriately if sustained hypertension develops.

Masked hypertension is present in approximately 8% of patients with CKD; as with white-coat hypertension, patients with masked hypertension are more likely to develop sustained

hypertension compared to patients with normotension.¹²⁰ In AASK, masked hypertension was more prevalent (43%) than typically observed in other cohorts, possibly reflecting an increased risk for sustained and masked hypertension among African Americans.⁹⁹ Masked hypertension is associated with increased risk of left ventricular hypertrophy, proteinuria and other subclinical markers of cardiovascular disease.^{59,99,112,116-118,125-132} In a meta-analysis of seven studies involving 11,502 subjects, masked hypertension was associated with increased risk for cardiovascular events (HR, 2.00; 95% CI, 1.6 to 2.5).¹²⁵ Thus, the presence of masked hypertension indicates high risk for cardiovascular disease; in some patients without home or ambulatory blood pressure measurements, masked hypertension is unrecognized and possibly undertreated. However, the therapeutic implications of masked hypertension are unclear. At this time, there are no studies evaluating the effect of antihypertensive treatment in patients with masked hypertension. Therefore, as with white-coat hypertension, future studies are needed to evaluate whether treating masked hypertension reduces the risk for adverse clinical outcomes.

Blood pressure measurement in dialysis patients

Blood pressure measurement in patients undergoing chronic hemodialysis presents some unique challenges. The marked changes in intravascular volume status before, during, and after dialysis result in blood pressure readings that differ significantly from one another. This has been a vexing problem for clinical nephrologists, since several studies that have attempted to assess whether pre or post dialysis pressures better track with outcomes have given conflicting results.¹³³ In addition, busy dialysis units may not follow recommended guidelines for blood pressure measurement resulting in readings that are higher than those obtained using standardized techniques.¹³⁴ Measurement of multiple blood pressure readings over time is conceptually attractive in this setting.

While blood pressures measured in the dialysis unit are predictive, a series of papers by Agarwal and colleagues has shown that home and ambulatory blood pressures correlate better with markers of hypertensive target organ damage and adverse clinical outcomes.^{105,135-137} Among 326 patients on long-term hemodialysis, increasing home and ambulatory systolic blood pressure was associated with increased risk for all-cause mortality (adjusted hazard ratios for increasing quartile of blood pressure were 2.51, 3.43, and 2.62 for ambulatory readings, vs 2.15, 1.7, and 1.44 for home-based measurements).¹⁰⁶ However, blood pressure measured before and after dialysis was not associated with mortality.¹⁰⁶ Thus, while frequent blood pressure measurement is essential for the safe conduct of the dialysis treatment, clinicians may consider carefully measured home blood pressures and/or ambulatory blood pressure in managing hypertension in dialysis patients.¹³⁸

Due to cost and patient burden issues, ABPM may have practical limitations in being used on a regular basis in the clinical setting. Home blood pressure monitoring, on the other hand, may be easier to implement, and, with increasing telehealth and computing capabilities, may be incorporated into the care of the hypertensive dialysis patient. Whether such an approach results in a reduction of hypertension related adverse clinical outcomes remains to be seen. Finally, central measures of blood pressure (as discussed below) are better predictors of outcomes in dialysis patients than brachial blood pressures.^{139,140}

Central aortic blood pressure and pulse wave velocity

Technologic advances in non-invasive measurement of vascular structure and function have generated considerable interest in the use of central aortic blood pressure and pulse wave velocity as predictors of cardiovascular risk.¹⁴¹ Recent excellent review articles detail the technical aspects of measurement, and predictive value of these measures in the general population¹⁴² and in chronic kidney disease.¹⁴³ These devices allow measurement of large artery stiffness represented by pulse wave velocity, and measures of central pressure including the augmentation index, central systolic and central pulse pressure.¹⁴⁴ The equipment requires modest training and time, but can be implemented in a clinical setting. In a cross sectional analyses of patients with CKD from the Chronic Renal Insufficiency Cohort (CRIC) Study, Townsend et al reported that central pulse pressures are positively and independently correlated with increasing brachial pulse pressure, older age, female sex, and the presence of diabetes mellitus.¹⁴⁵ These measures independently predict risk of cardiovascular disease in the general population, though only augmentation index added predictive value to conventional measures of blood pressure.¹⁴⁶ Recently, measures of arterial stiffness estimated based on home blood pressure readings have also been shown to have prognostic significance.¹⁴⁷

The role of centrally measured blood pressure as a target for antihypertensive drug therapy is less well defined. In a substudy of participants enrolled in the Anglo-Scandinavian Cardiac Outcomes Trial (ASCOT) trial, there was no difference in brachial systolic BPs between treatment groups; however, compared to atenolol based therapy, amlodipine based therapy resulted in significantly lower central aortic systolic pressure (4.3 mmHg lower; $P < 0.0001$) and central aortic pulse pressure (3.0 mmHg lower; $P < 0.001$). Additionally, elevated central pulse pressure was associated with increased risk for a composite outcome that included cardiovascular events and renal impairment.¹⁴⁸ Other studies have shown that ACE/ARB based therapy may be more effective in lowering central aortic pressure than other antihypertensive drug therapies.^{149,150} Whether targeting central blood pressure improves clinical outcomes remains to be tested in prospective clinical trials.

Conclusions

Carefully measured office blood pressure remains important in the diagnosis and management of hypertension. Clinicians can use home and ambulatory blood pressure monitoring to optimize risk stratification and facilitate achievement of blood pressure control. It is likely that a systematic approach incorporating all modes of blood pressure measurement will optimize the management of the hypertensive patient as outlined in a recent position paper from the American Society of Hypertension (Figure 3).⁴ Central measures of blood pressure and pulse wave velocity are promising, but await further research to define their role in the management of the hypertensive patient.

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Figure 1.

Ambulatory blood pressure monitoring results for a patient with hypertension

Legend: ABPM results indicate elevated daytime blood pressures with a normal dipping pattern (night/day ratio < 0.90) and a morning surge in blood pressure between 0500 and 0700.

Figure 2.

Clinic and nighttime blood pressure by dipping status in AASK.

Legend. Average clinic (grey) and nighttime blood pressure (black bars) in reverse dippers (night/day BP ratio > 1), nondippers (night/day ratio ≤ 1 and > 0.9), and dippers (night/day ratio < 0.9). Adapted and reproduced from Pogue et al⁹⁹ with permission of Wolters Kluwer Health.

Figure 3.

Algorithm for incorporating home and ambulatory blood pressure measures in the management of hypertension

Legend. Adapted and reproduced from Pickering et al⁴ with permission of the American Society of Hypertension.

Table 1

Blood pressure classification

Measurement location/type	Optimal	Normal	Pre-hypertension	Abnormal
Clinic		< 120/80	120-139/80-89	140/90
Home		135/85		> 135/85
Ambulatory				
Daytime	< 130/80	< 135/85		> 140/90
Nighttime	< 115/65	< 120/70		>125/75
24-Hour	< 125/75	< 130/80		> 135/85

Note: values are given as systolic/diastolic and are reported in millimeters of mercury.

Values are based on various data sources.^{12,13,20,53}

selected studies comparing home with office blood pressure in predicting long term outcomes.

Table 2

Study	Population	Follow up	Outcome	Association between BP and outcome	Conclusion
PAMELA ⁶⁵	General population (n=2051)	10.9 y	Mortality	β coefficient for change in risk per 1-unit change in BP: 0.03 for office SBP and 0.04 for home SBP	Risk of death increased more with a given increase in home vs office BP
Ohasama ⁴¹	General population, age >40 y (n=1789)	6.6 y	Mortality	Relative hazard for risk of mortality per 1-mm Hg change in BP: 1.011 (p<0.05) for home BP; 1.001 (NS) for clinic BP	Home BP measurement has a stronger predictive power for mortality than does office BP
SHEAF ⁵⁹	Elderly hypertensives (n=4939)	3.2 y	Fatal or nonfatal cardiovascular events	Adjusted hazard ratio for 1-mm Hg change: 1.02 (p<0.001) for home SBP; 1.01 (p=0.09) for office SBP	Home BP measurement has a better prognostic accuracy than office BP measurement

Abbreviations: PAMELA, Pressioni Arteriose Monitorate e Loro Associazioni; SHEAF, Self-Measurement of Blood Pressure at Home in the Elderly; Assessment and Follow-up; BP, blood pressure; SBP, systolic blood pressure; NS, nonsignificant.

Table 3

major studies comparing ambulatory with office blood pressure in predicting long term outcomes.

Population	Follow up	Outcome	HR (95% CI) of ABPM measure ^a	Conclusion/Notes
5,292 untreated hypertensives ¹⁵¹	8.4 y	CV mortality	Daytime : 1.12 (1.06-1.18) Nighttime : 1.21 (1.15-1.27)	Clinic BP not predictive of CV mortality after adjusting for ambulatory BP; nighttime SBP (but not daytime SBP) predictive of CV morbidity and mortality in models including both variables
3,957 patients referred for ABPM ¹⁵²	6.5 y	All-cause mortality	Awake : 1.04 (0.94-1.15) Sleep : 1.15 (1.06-1.24)	Non-dippers at increased risk for all-cause mortality regardless of awake BP
1,700 subjects from general population ⁸⁷	9.5 y	CV morbidity & mortality	Daytime : 1.33 (1.20-1.48) Nighttime : 1.27 (1.18-1.38) Clinic : 1.18 (1.09-1.29)	Non-dipping a significant risk factor only in subjects with elevated daytime BP; clinic BP no longer significant after adjusting for ambulatory BP
277 patients with CKD ¹⁰¹	3.5 y	1 ESRD 2 Death	ESRD outcome Dipping * : 1.04 (0.73-1.47) Nighttime **: 1.55 (0.90-2.66) Daytime **: 2.03 (1.08-3.82) Death outcome Dipping * : 1.42 (1.06-1.90) Nighttime **: 1.90 (1.18-3.11) Daytime **: 0.74 (0.43-1.26)	Ambulatory BPs are stronger predictors of ESRD or death than clinic BPs; non-dipping is a risk factor for ESRD independent of clinic BP
436 CKD patients ¹⁰²	4.2 y	1 CV events 2 ESRD or death	CV events outcome Daytime #: 3.07 (1.54-6.09) Nighttime #: 4.00 (1.77-9.02) ESRD or death outcome Daytime #: 1.85 (1.11-2.08) Nighttime #: 2.54 (1.41-4.57)	Office BP not a significant predictor of either outcome; patients with poorly controlled nighttime BP at increased risk for ESRD/death regardless of daytime BP; non-dippers and reverse dippers at increased risk for CV events and ESRD/death

* Adjusted for 24hr systolic ambulatory BP;

** Models include both day and night ambulatory BP;

5th vs 3rd quintile for daytime, 5th vs 2nd quintile for nighttime.

^a) HRs based on SBP measurements.

Abbreviations: ABPM, ambulatory blood pressure monitoring; SBP, systolic blood pressure; BP blood pressure; ESRD, end-stage renal disease; CKD, chronic kidney disease; HR, hazard ratio; CI, confidence interval; CV, cardiovascular.