BP Measurement Techniques

What They Mean for Patients with Kidney Disease

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Abstract

Patients with CKD typically have hypertension. Manual BP measurement in the office setting was used to define hypertension, establish eligibility, and assess BP targets in the epidemiologic studies and early randomized, controlled trials that inform current management of hypertension. Use of automated oscillometric devices has largely replaced manual BP measurement in the office and clinical trials. These newer devices may reduce the white coat effect and facilitate guideline-adherent measurement protocols. Obtaining BP measurements outside of the office with home and ambulatory BP monitoring is now more common. Out of office BPs are especially important in patients with CKD, because reduced GFR and proteinuria are associated with masked hypertension (normal office BP and elevated BP outside of the office), elevated nighttime BP, and abnormal diurnal variation in BP, all of which are associated with higher risk for target organ damage and adverse outcomes. Also, it is now feasible to routinely measure central BP and central hemodynamics. These measures are of greater importance to patients with CKD given the higher prevalence of increased sympathetic tone, arteriosclerosis, and inflammation as well as impaired sodium excretion and endothelial dysfunction, which lead to alterations in central BPs in this population. In this review, we describe various BP measurement techniques and how they apply to the care of patients with CKD.

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Introduction

Hypertension is a strong independent risk factor for cardiovascular disease, with observational studies showing a continuous and linear relationship between BP and cardiovascular risk (1). Hypertension is common in patients with CKD, and it can be a cause or consequence of CKD (2). The prevalence of hypertension in patients with CKD, when defined as BP level ≥140/90 mm Hg, is inversely related to the eGFR—increasing from 67% in those with eGFR>60 ml/min per 1.73 m^2 to 92% in those with eGFR<30 ml/min per 1.73 m^2 (2,3). Furthermore, patients with CKD are at higher risk for hypertension-related adverse outcomes, including cardiovascular disease (4). Therefore, management of hypertension is particularly important in patients with CKD.

The diagnosis and management of hypertension are still predominantly on the basis of office BPs. However, patients with CKD are prone to abnormal BP patterns when BP is measured outside of the office at home and with ambulatory BP monitoring or when central BPs are assessed. The purpose of this review is to discuss various BP measurement techniques and how they apply to the care of patients with CKD.

Automated Office BP Monitoring

The diagnosis and optimal management of hypertension necessitate obtaining an accurate assessment of patients' true hypertensive status and risk of end organ damage. Traditional manual office BP measurement relies on the use of aneroid sphygmomanometers. Oscillometric devices, which are more commonly used now, overcome some of the disadvantages of auscultatory measurements (5). Office-based BP measurements, whether using the auscultatory or the oscillometric method, have some inherent limitations, including an inability to assess diurnal variation and the "white coat effect," a transient increase in BP observed in some patients when a medical professional is present in the room (6,7). Despite these limitations, it is likely that office-based BP measurements will continue to be the primary technique for both the diagnosis and management of hypertension. Current treatment recommendations are on the basis of clinical trials that used office BP measurements.

The use of automated office BP devices that take multiple consecutive BP readings with the patient sitting and resting alone has been shown to decrease the white coat response compared with single manual measurements (8). Although some studies have shown that automated office BP shows a stronger correlation with average awake BP on ambulatory BP monitoring compared with routine measurements, this finding is not consistent. In a clinical trial of 555 patients with hypertension who were randomized by clinic to ongoing use of manual office BP or automated office BP, mean manual office BP at baseline was similar in both groups (150/81 versus 150/82 mm Hg) (9). After randomization, mean office BP was significantly lower in clinics randomized to automated compared with manual measurement (136/78 versus

141/80 mm Hg). However, the average awake ambulatory BP was not different between the groups (133/74 versus 135/76 mm Hg); automated office BP readings were significantly closer than manual readings to average awake ambulatory BP.

The Systolic Blood Pressure Intervention Trial (SPRINT), which showed lower risk for cardiovascular outcomes with intensive BP lowering, measured BP with an automated device in triplicate at 1-minute intervals after a specified 5 minutes of seated rest in a quiet room without an observer in the room at most sites. A study by Agarwal (10) compared BPs measured similar to those in the SPRINT protocol with routine BPs and ambulatory BPs in 275 participants with CKD who were normotensive. The mean systolic automated office BP was 12.7 mm Hg lower compared with routine measurement and 7.9 mm Hg lower than average awake ambulatory BP. Although this study showed that neither the routine measurement nor the automated office BP were able to predict average awake ambulatory BP accurately, automated office BP was a stronger determinant of echocardiographic left ventricular hypertrophy compared with routine measurement. The SPRINT ambulatory BP ancillary study (11), in which ambulatory BP monitoring was performed in 897 SPRINT participants, found mean automated office systolic BP of 119.7 mm Hg and mean daytime ambulatory systolic BP of 126.5 mm Hg in the intensive group and mean automated office systolic BP of 135.5 mm Hg and mean daytime ambulatory systolic BP of 138.8 mm Hg in the standard group. These results indicate a lack of agreement between automated office BP and daytime ambulatory BP that may be affected by the level of the BP target.

Although some guidelines now recommend use of automated office BP as the preferred method of in-office BP measurement (12), the 2017 American College of Cardiology/American Heart Association Task Force (ACC/AHA) recommendations do not specifically advocate this, instead noting that "there is growing evidence supporting the use of automated office BP" (13). When using automated office BP, some experts recommend a threshold value for diagnosis of hypertension of ≥135/85 mm Hg in the general population (12,14). All office-based BP measurements, whether manual or automated, should follow guidelines regarding proper patient positioning, correct cuff size and placement, quiet rest, and more than one reading averaged to represent the clinic BP for that visit (15).

Although nearly all of the clinical trials informing management of hypertension used office BP to evaluate eligibility and as the target BP, office BP measurements alone may not be sufficient to guide hypertension management in patients with CKD. Studies have shown a significant prevalence of masked hypertension in this population (apparently normotensive in office and hypertensive out of office) (16,17); thus, out of office measurements should be considered in this population.

Home BP Monitoring

The wide availability of automated electronic devices has increased use of home BP monitoring. The US Preventive Services Task Force (USPSTF) recommends out of office BP measurements for confirmation of diagnosis of hypertension. Although ambulatory BP monitoring is preferred, home BP measurements using appropriate protocols are an acceptable alternative method of confirmation (18). Home BP is more strongly associated with target organ damage and progression of CKD compared with routine office BP measurements (19,20). Home BP reduces the misclassification of hypertension due to the white coat and masked effects seen with office-based BP measurements; however, the reproducibility of home BP in diagnosis of masked uncontrolled hypertension was lower than ambulatory BP in patients with CKD (21).

Some experts have previously recommended a threshold value for diagnosis of hypertension using a home BP of ≥135/85 mm Hg in the general population correspondent to office BP of ≥140/90 mm Hg (12,22); the 2017 ACC/AHA guidelines note home BP of 130/80 mm Hg as the correspondent value to office BP of 130/80 mm Hg (13). Patients should be advised on a monitoring schedule and educated about the correct technique of BP measurement using a validated home BP device (13). Wrist and finger monitors should be avoided due to inaccurate measurements.

Self-monitoring enhances patient involvement, and it could potentially increase adherence with treatment and improve rates of BP control. However, the implementation of such a system may be limited by reporting bias (where patients may inaccurately report home BPs), cost, and patient familiarity with the technology. Home BP telemonitoring, with automated teletransmission of BP data to the treating physician or team at regular intervals, may overcome reporting bias, and it may represent a useful tool to improve BP control. The Targets and Self-Management for the Control of BP in Stroke and at Risk Groups Study, in which patients were randomized to usual care or self-management (self-monitoring BP and self-titration of antihypertensive medications combined with home BP telemonitoring), showed significantly better BP control in the self-management group (23). A cluster randomized trial with 450 patients comparing usual care with home BP telemonitoring (transmission of BP data to pharmacists who adjusted antihypertensive therapy) showed better office BP control in the home BP telemonitoring group, with the effect persisting during the 6 months of post-intervention follow-up (24). Home BP telemonitoring has also been shown to result in better control of ambulatory BP than usual care (25).

These studies suggest that home BP has the potential for greater BP improvement if accompanied by specific strategies, such as telemonitoring and responsive action by the treating provider. No randomized trials have evaluated whether targeting home BPs reduces adverse clinical outcomes compared with office-based hypertension management.

Ambulatory BP Monitoring

Ambulatory BP monitoring has been available since the 1980s. Briefly, the protocol involves application of an appropriate sized cuff to the nondominant arm and measurement of BP typically every 30 minutes during the day and night for a 24-hour period (26). Patients are instructed

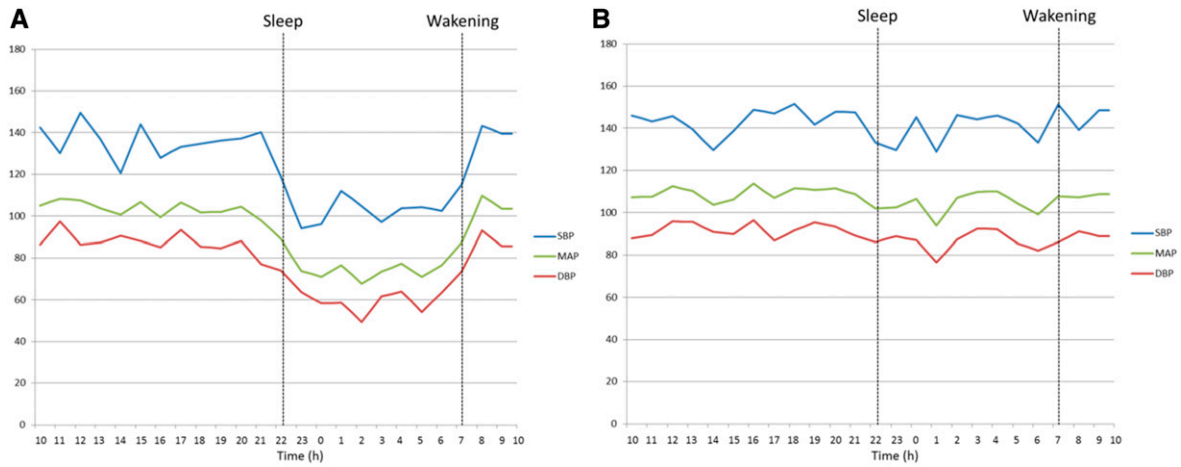

Figure 1. | Ambulatory BP monitoring results for two representative patients. (A) Ambulatory BP monitoring results for a patient with hypertension and elevated daytime BPs with a normal dipping pattern (night-to-day ratio <0.90) and a morning surge in BP between 5:00 and 7:00 AM. The patient in B has elevated daytime and nighttime BPs with a nondipping pattern (night-to-day ratio ≥0.90). DBP, diastolic BP; MAP, mean arterial pressure; SBP, systolic BP. Modified from ref. 28, with permission.

to follow their normal daily activities, keep their arm still while the BP is being measured, and keep a diary of sleep and wake periods (17,26). Ambulatory BP monitoring provides estimates of 24-hour, daytime, and nighttime BP along with other calculated variables, such as dipping status (the change in BP from day to night) (Figure 1) and BP variability. BP load, the proportion of BP readings above accepted cutoffs, is associated with target organ damage and adverse outcomes. However, BP load does not improve risk stratification when added to models including 24-hour ambulatory BP (27). Although prior cutoffs were higher (28), the recent ACC/AHA guidelines recommend the following cutoffs for ambulatory BP monitoring: 125/75 mm Hg for 24-hour BP, 130/80 mm Hg for daytime BP, and 110/65 mm Hg for nighttime BP (13). When office and ambulatory BP measurements are available, patients can be classified as controlled (normal office and ambulatory BP), white coat hypertensive (elevated office and normal ambulatory BP), masked hypertensive (normal office and elevated ambulatory BP), and sustained hypertensive (elevated office and ambulatory BP). CKD is associated with abnormal ambulatory BP patterns, including elevated ambulatory BP and nondipping, masked, and sustained hypertension.

Low eGFR has been associated with masked and sustained hypertension as well as nighttime hypertension and nondipping (17,29,30). In 1492 participants from the Chronic Renal Insufficiency Cohort (CRIC) Study, masked hypertension was associated with lower eGFR compared with in participants with controlled office and ambulatory BP (17). Proteinuria is also associated with abnormal ambulatory BP profiles, including sustained hypertension, nighttime hypertension, and masked hypertension (16,17,31,32). The association between proteinuria and abnormal ambulatory BP profiles may be stronger than that between eGFR and abnormal ambulatory BP—in two studies, proteinuria but not low eGFR was associated with nighttime hypertension and masked hypertension (16,32). The mechanisms that lead to elevated office BP in patients with low eGFR and proteinuria, such as endothelial dysfunction, increased sympathetic tone, sodium retention, and inflammation, likely also contribute to the higher risk for abnormal ambulatory BP profiles in patients with CKD.

Not only are abnormal ambulatory BP profiles more prevalent in patients with CKD, but as in the general population, abnormal ambulatory BP profiles are also associated with higher risk for adverse clinical outcomes. In the African American Study of Kidney Disease and Hypertension, elevated 24-hour, daytime, and nighttime BP measurements were associated with higher risk for cardiovascular events, regardless of office BP (33). However, elevated ambulatory BPs were only associated with higher risk for kidney events in those with controlled office BP (systolic BP <130 mm Hg) (33). In two separate CKD cohorts from Italy and China, masked and sustained hypertension were associated with higher risk for all-cause mortality, kidney events, and cardiovascular disease (34,35). Ambulatory BP monitoring is also important for identifying patients with pseudoresistant hypertension and white coat hypertension, both of which are low-risk phenotypes (31,36). The preponderance of evidence suggests that abnormal ambulatory BP patterns, more prevalent in patients with low eGFR and proteinuria, are associated with higher risk for a wide range of adverse outcomes in patients with CKD. A lack of long-term clinical trials with hard outcomes leaves unanswered the question of whether targeting ambulatory versus office BP would result in lower rates of these adverse outcomes.

Central BP Monitoring

Central BP can be assessed by direct measurement *via* invasive cardiac catheterization, by applanation tonometry of the carotid or radial artery, and with cuff-based oscillometry at the brachial artery (37). Newer brachial cuff–based devices even allow for measurement of ambulatory central BP. For example, the oscillometric Mobil-O-Graph

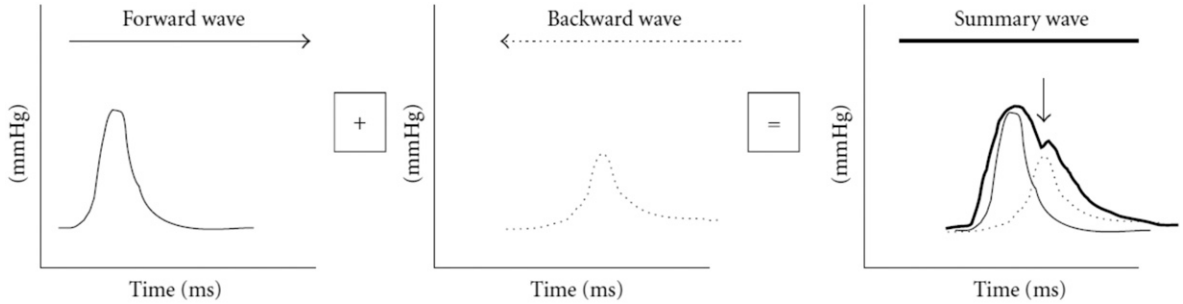

Figure 2. | Central pressure is a product of the forward pressure wave resulting from ventricular contraction as well as backward pressure waves. Reprinted from ref. 56, with permission.

device (IEM, Stolberg, Germany) is a brachial oscillometric 24-hour ambulatory BP monitor. In addition to traditional brachial BP, brachial waveforms are recorded by inflating the cuff to the diastolic level and maintaining this pressure for approximately 10 seconds (38). Central BP and aortic pulse wave velocity are estimated from the brachial waveforms.

Central (aortic) systolic BP is a product of the forward pressure wave resulting from ventricular contraction as well as backward pressure waves. Backward pressure waves return to the aorta after reflection from arterial branch points and atherosclerotic plaques (Figure 2) (39). The time during the cardiac cycle that the backward wave returns to the aorta depends in large part on heart rate and arterial stiffness, which can be assessed by measuring pulse wave velocity. Elevated pulse wave velocity and low heart rate are associated with increased central systolic BP. As a result of these factors and others, there is significant variability in central systolic BP between individuals with similar peripheral systolic BPs. In a large observational study, over 70% of participants with high-normal peripheral BP had central BPs similar to those with stage 1 hypertension (40).

Despite the fact that the kidneys are exposed to BPs more similar to central than peripheral BP, the association between central BPs and kidney function (proteinuria and eGFR) is not as well documented as the association between peripheral BPs and kidney function. Among patients with diabetes, peripheral and central BPs were associated with urine albumin excretion, but the area under the curve for peripheral BP was higher than that for central BP (41). In the Japan Morning Surge-Target Organ Protection Study comparing morning with evening dosing of candesartan, change in central BP with therapy was associated with change in the urine albumin-to-creatinine ratio (42). In the CRIC Study, eGFR and 24-hour urine protein were associated with central pulse pressure in univariable analyses, but neither were retained in multivariable models (43). Also in the CRIC Study, central BPs did not increase the explained variance in 24-hour urine protein beyond peripheral BPs. However, pulse wave velocity, a measure of central arterial stiffness, did increase explained variance in proteinuria (44). Similarly, the augmentation index, a measure of the backward pressure wave and a marker of arterial stiffness, is associated with higher proteinuria and lower creatinine clearance (45). Given the heterogeneity of these results, further studies are needed to better understand the relationship between kidney function and central BPs and other related parameters, such as augmentation index and pulse wave velocity, that are also available when central BPs are measured.

In the general population with normal kidney function, central BPs are more strongly associated with vascular damage and cardiovascular events than brachial BPs (46,47). Results are mixed in the CKD population. In the CRIC Study, 2602 participants free of heart failure had peripheral and central BPs measured along with carotid-femoral pulse wave velocity (48). In adjusted analyses, pulse wave velocity and brachial systolic and pulse pressures were associated with incident heart failure. However, only central pulse pressure, but not central systolic BP, was associated with incident heart failure (48). In patients with ESKD, central BPs have been associated with adverse outcomes. In a study of 180 patients with ESKD undergoing hemodialysis, carotid pulse pressure and augmentation index were both associated with higher risk for all-cause mortality (49). Additionally, pulse wave velocity is associated with higher risk for all-cause and cardiovascular mortality in patients with ESKD (49,50). Although the association between pulse wave velocity and adverse outcomes in patients with CKD is well established, further studies are needed to determine the prognostic significance of central BPs in patients with CKD. Measuring central ambulatory BP combines the strengths of both anatomic location (central/aortic BP) and duration (ambulatory), and it may be critical to better understanding the relationship between hypertension and adverse cardiovascular and kidney outcomes. Finally, although most antihypertensive agents lower peripheral and central BPs to a similar degree, angiotensin-converting enzyme inhibitors and nitrates may have a greater central BP–lowering effect, whereas β-blockers, atenolol in particular, lower brachial BP to a greater extent than central BP (37).

Smartphone and Other Device-Based BPs

Given the improvement in risk stratification with home and ambulatory BPs, there is a great deal of enthusiasm for using smartphones and watches to measure BP outside of the office setting. A number of Android-based applications and at least one iPhone-based application purport to transform phones into BP measurement devices (51,52). There are no reports on the accuracy of the Android-based applications; an assessment of the iPhone-based application found it to

be highly inaccurate (52). Other similar direct to consumer–marketed devices are also available. For example, Nokia now sells the Body Cardio scale, which claims to be capable of measuring weight, fat mass, muscle mass, bone mass, hydration status, and pulse wave velocity. There are no published studies evaluating the accuracy of the Body Cardio pulse wave velocity measurements. Although it is likely that phone-, watch-, or scale-based devices will eventually be capable of accurate measurement of peripheral and central BPs as well as measures of vascular health, such as pulse wave velocity, use of these devices for measurement of even brachial BP is not currently advisable.

Increasing Clinical Relevance of Out of Office BP Measurements

In November 2015, the USPSTF recommended "obtaining measurements outside of the clinical setting for diagnostic confirmation before starting treatment" of hypertension (18). This recommendation is on the basis of the facts that about one in four patients with elevated office BP will have normal ambulatory or home BP (white coat hypertension) and that patients with white coat hypertension are at low risk for adverse outcomes. The USPSTF guidelines do not comment on masked hypertension or other measures, such as central BP. Previous guidelines from other organizations, including the report from the panel members appointed to the Eighth Joint National Committee and the European Society of Hypertension (ESH), continue to recommend office BP as the "gold standard" for diagnosis and management of hypertension (53,54). However, the ESH and the latest guidelines from the ACC/AHA recommend out of office monitoring in certain circumstances, including suspected white coat and masked hypertension (13,55). No guidelines recommend measurement of central BP in the routine diagnosis or management of hypertension (Table 1).

Recommendations for Practice

Accurate assessment of BP may be one of the most important aspects of many clinic visits. It is imperative that proper measurement technique and procedures be

Table 1. Comparison of BP measurement techniques

Consideration	Manual Office BP	Automated Office BP	Home BP	Ambulatory BP	Central BP
Description	Traditional manual office BP	Office BP using oscillometric device	Measurement of BP in the home; typically using an oscillometric device	Automated measurement of BP over the course of 24 h; BP typically measured every 30 min during the day and night	Measured using applanation tonometry of the carotid or radial artery or with cuff-based oscillometry at the brachial artery
Monitoring schedule	Office visit	Office visit	Long term	24 h, Including nighttime	Office visit
Patient education required	No	No	Yes	Yes	No
White coat effect	Likely	Reduced versus manual BP	No	No	Possible
Availability in most physician offices	Yes	Yes	NA	Limited	Limited
Assessment of nighttime BP and nocturnal dipping	No	No	No	Yes	No
Assessment of central hemodynamics	No	No	No	No[a]	Yes
Evidence showing association with adverse outcomes	Strong	Moderate	Moderate	Strong	Moderate
Diagnosis thresholds for hypertension, mm Hg (ESH/ESC 2013, HCGC 2017)	140/90[b]	135/85[c]	135/85	Daytime: 135/85; nighttime: 120/70	NA
Diagnosis thresholds for hypertension, mm Hg (ACC/AHA 2017)	130/80 (Does not specify routine office BP versus automated office BP		130/80[d]	Daytime: 130/80[d]; nighttime: 110/65[d]	NA

NA, not applicable; ESH/ESC, European Society of Hypertension/European Society of Cardiology Task Force; HCGC, Hypertension Canada Guidelines Committee; ACC/AHA, American College of Cardiology/American Heart Association Task Force.
[a]Some devices are capable of both 24-hour ambulatory BP monitoring and central pressure monitoring.
[b]The ESH/ESC guidelines do not specify routine office BP versus automated office BP.
[c]The HCGC guidelines specify a routine office BP threshold of 140/90 mm Hg and an automated office BP threshold of 135/85 mm Hg.
[d]Correspondent values to office BP of 130/80 mm Hg as noted in the ACC/AHA 2017 guidelines.

followed for this assessment, including the use of validated and properly calibrated BP devices, proper patient positioning, a quiet rest period, and measurement of more than one BP. Automated office BP measurement may be preferable to reduce the white coat effect. Out of office BP measurements (home or ambulatory) can be done to confirm the diagnosis of hypertension, and they are helpful for ongoing management of hypertension. However, no clinical trials have evaluated whether management on the basis of out of office readings reduces risk for adverse outcomes compared with office-based BP management. Smartphone and other device-based applications do not provide accurate-enough BP readings for clinical practice. Finally, central BP may be critically important in patients with CKD, but further research is needed to inform the use of central BP in the management of hypertension.

Disclosures

None.

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