# Chapter 2
# Central BP Monitoring, Home BP Monitoring, Ambulatory BP Monitoring in CKD

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Hypertension is common among patients with chronic kidney disease (CKD) and the prevalence of hypertension increases as overall kidney function deteriorates, ranging from 60 to 100% depending on the population studied [1]. This chapter will specifically discuss the role of central blood pressure (BP) monitoring, home BP monitoring (HBPM), and ambulatory BP monitoring (ABPM) in the CKD population.

## Central BP Monitoring in CKD

For over a century, the gold standard for BP measurement has been the peripheral brachial BP by conventional sphygmomanometry. Despite being a traditional predictor of cardiovascular (CV) risk [2], peripheral brachial BP does not accurately represent central aortic pressure which is intuitively more relevant to the true BP burden experienced by the major organs. While the mean and diastolic BP remain mostly unchanged, the systolic BP and pulse pressure (the difference between the systolic and diastolic BP) are amplified from the aortic root to the peripheral brachial artery. Central aortic BP and arterial compliance can now be reliably assessed using noninvasive applanation tonometry [3] and the reproducibility of these measurements has been confirmed in the CKD population [4–6]. Emerging data suggest that measurements of central aortic BP and arterial compliance may be more robust

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predictors of CV outcomes than traditional peripheral brachial BP in various populations including CKD [7–10].

## Central BP Measurements and Outcomes in CKD

Central aortic systolic, diastolic, mean, and pulse pressures can be obtained from the central aortic pressure waveforms, which are estimated through a mathematical transformation of the radial or carotid arterial pressure waveforms captured by noninvasive applanation tonometry [3, 11, 12]. Compared to carotid artery applanation tonometry, radial artery applanation tonometry is more comfortable for the patients and easier to use in clinical settings.

The arterial pressure wave forms are the summation of the forward transmissions of the cardiac pressure waves generated by systolic, and the backward wave reflections generated by the peripheral vascular system at the interface between large arteries (conduit) and small (resistant) arteries. The shape of arterial pressure waveforms depends on three key factors, including (1) the amplitude and duration of the ventricular ejection, (2) the amplitude of the reflected wave, and (3) the velocity of the reflected wave returning from the periphery. Under normal physiological conditions, the reflected waves return to the central arteries in very late systole or early diastole during the same cardiac cycle, which augments coronary perfusion. When the reflected waves return earlier in systole due to increased pulse wave velocity (PWV), proximal site of wave reflection, or longer ejection time, the cardiac systolic pressure and workload are increased and the coronary perfusion is decreased.

Central systolic BP increases with age [13]. Before age 50, the increase in central systolic pressure is primarily due to greater amplitude of wave reflection, however, after age 50, the increase in central systolic pressure is mostly due to systolic augmentation, related to wave reflection, returning earlier because of increasing PWV [14]. Slower heart rates lead to longer ejection time and increase the possibility of augmenting systolic pressure as the wave reflection returns earlier during the cardiac cycle. Small statures also lead to earlier return of the wave reflection because sites of wave reflection are closer to the aorta. In a cross-sectional analysis of a large cohort of 2532 CKD patients enrolled in the Chronic Renal Insufficiency Cohort (CRIC) study, central aortic pulse pressure was independently correlated with age, sex, weight, diabetes, and heart rate [15]. In addition, the proportion of high central aortic pulse pressure of $\geq 50$ mmHg appears to increase progressively as the stage of CKD advances. In a study of 180 end-stage renal disease (ESRD) patients for more than 4 years, central carotid pulse pressure was shown to be a strong independent predictor of all-cause and CV mortalities while peripheral brachial BP and pulse pressure failed to show any significant predictive value [8].

Pulse wave analysis (PWA) in a group of 375 CKD patients with mean age of 60 years and estimated glomerular filtration rate (eGFR) of 48 mL/min/1.73 $m^2$ showed that both aortic systolic and pulse pressure derived from PWA were significantly associated with carotid intima-media thickness (IMT) while only aortic pulse pressure was significantly associated with the presence of carotid plaque [16].

## Central Arterial Compliance Measurements and Outcomes in CKD

PWV remains the gold standard in measuring arterial stiffness [17]. Increasing PWV due to stiffening of the aorta is mostly seen with aging [18] and observed in isolated systolic hypertension in the elderly, sustained systolic–diastolic hypertension in middle age [19], as well as in populations with metabolic syndrome [20], impaired glucose tolerance or type 2 diabetes [21, 22], proteinuria [23], CKD, or ESRD [24, 25].

Aortic PWV can be determined by capturing arterial waveforms from two sites, typically carotid and femoral, and by measuring the distance between the two sites and the time required for the waves to travel [12]. Compared to ultrasonography or magnetic resonance image-based approach, applanation tonometry is easier to use, less expensive, and less time consuming.

Arterial compliance can be indirectly assessed using the augmentation of the central aortic pressure waveform which is defined as the amount of pressure added to the systolic pressure peak due to the wave reflection. The ratio of the augmentation pressure portion to the total central pulse pressure is termed augmentation index (AIx) and expressed in percentage. The AIx is sometimes "normalized" to a heart rate of 75 bpm.

Central aortic stiffness assessed by PWV is a strong independent predictor of all-cause and CV mortalities in ESRD patients [26, 27]. Central carotid AIx and pulse pressure have also been shown to be predictors of all-cause and CV mortalities while peripheral brachial systolic and pulse pressure showed less predictive value [8, 28]. It is worth noting that a study of young nondiabetic dialysis patients failed to show independent predictive value of AIx in all-cause mortality [29]. More recently in a study of CKD patients and kidney transplant recipients (mean age of 53 years and eGFR of 44 mL/min/1.73 $m^2$), central pulse pressure derived from peripheral PWA also failed to show significance in determining central aortic PWV and left ventricular mass index [30].

In nondiabetic CKD patients, higher AIx and higher baseline proteinuria were the only independent predictors of decline in GFR at 1 year [31]. In stage 4 or 5 CKD, a higher PWV and AIx as well as baseline eGFR, proteinuria, and smoking were shown to be independent predictors for the progression to ESRD [32]. A cross-sectional examination of a large cohort of 2144 CKD patients in the CRIC study found that brachial systolic blood pressure (SBP) was significantly correlated with proteinuria in both diabetics and nondiabetics [33]. Independent of brachial SBP, central aortic stiffness by PWV was also found to be significantly correlated with proteinuria in diabetics while peripheral brachial pulse pressure, central aortic systolic, and pulse pressure had no significant correlation with proteinuria in both diabetics and nondiabetics.

Furthermore, a study of stage 5 CKD patients showed improvement in arterial compliance by reduction in PWV and AIx, at 3 months after kidney transplant [34], suggesting a possible cause–effect relationship between impaired renal function and arterial stiffness. While the reductions in AIx were comparable, patients older than

**Table 2.1** Utility of central BP monitoring in CKD

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| Central BP assessment obtained by aortic or carotid measurements |
| Provides more accurate assessment of true BP burden of vital organs |
| Better assessment of BP-related cardiovascular risk |
| Arterial compliance by aortic or carotid PWV and AIx |
| Better assessment of the burden of atherosclerosis and vascular injury |

50 years of age appeared to have more pronounced reduction in PWV than the younger patients.

Emerging data suggest that measurements of central BP and arterial compliance are robust predictors of CV outcomes when compared with traditional peripheral brachial BP. Measuring central BP and arterial compliance could become an increasingly important part of routine clinical assessment of BP and related CV risks and treatment effects in high-risk populations such as patients with CKD. The utility of central BP monitoring in CKD patients is shown in Table 2.1.

## HBPM in CKD

Office BP measurements significantly overestimate the burden of hypertension in patients with CKD and can lead to an overdiagnosis of hypertension in this population. When compared with ABPM in patients with CKD, HBPM has been shown to be superior to office measurements for the diagnosis of hypertension [35]. One week of home BP readings averaging more than 140/80 mmHg are associated with an awake ambulatory BP of more than 130/80 mmHg, which is considered "hypertensive" in the CKD population. These thresholds of SBP and DBP have been found to have both a sensitivity and specificity of more than 80 %, making HBPM useful upon which to base clinical decisions. HBPM also appears to be more accurate than office BP readings to identify CKD patients with white coat hypertension (WCH) and masked hypertension [35]. HBPM can be very useful in both diagnosis and management of hypertension in hemodialysis patients, where BP management is often difficult due to massive volume shifts [36]. Home BP readings are more reproducible from 1 week to the next when compared to pre or post-dialysis BP readings [37]. Home BP is recommended as a guide to the management of BP in dialysis patients and is useful to track changes in BP induced by reducing estimated dry-weight [37, 38]. Studies have shown that HBPM is superior when compared to pre-dialysis BP readings to manage antihypertensive therapy adjustments [39] and improves BP control [40]. The frequency and timing of HBPM in dialysis patients are important, since home BP increases on average at a rate of 4 mmHg for every 10 h of elapsed time after a recent dialysis treatment [41]. Measurement of BP soon after dialysis or just before dialysis will underestimate, or overestimate the BP, and therefore it is important to measure the BP at various intervals following dialysis [42]. It is recommended that BP be measured twice when waking up in the morning and twice before going to sleep following a midweek dialysis for 4 days [43].

These repeated midweek measurements provide an adequate number of readings to diagnose and manage hypertension. For stable dialysis patients, monthly home measurements of interdialytic BP should be encouraged. Peritoneal dialysis patients differ from hemodialysis patients in that they do not have large fluid shifts and undergo daily dialysis treatments with more stable fluid balance and BP measurements. HBPM has also been shown to be very useful in the diagnosis of hypertension in peritoneal dialysis patients [44].

## Home BP Measurement and CKD Outcomes

Home BP readings provide more accurate readings than office or clinic BP readings in CKD and ESRD patients when compared to ABPM. A number of studies have attempted to address whether HBPM correlates with target organ damage, increased CV risk and progression of CKD.

## Studies in CKD Population

Out-of-office BP readings in CKD patients are strongly associated with target organ damage [45]. HBPM has been shown to correlate with proteinuria and decline in eGFR [46]. Home BP measured in the morning had the strongest correlation with annual decline in eGFR [47] and as compared to office BP, HBPM is a significant predictor of decline in renal function and development of ESRD [48]. Proteinuria has been shown to be the strongest correlate of SBP by any BP measurement technique and this has been correlated more closely with both home, and ambulatory blood pressure (ABP) measurements when compared to office values [49]. In a prospective study of CKD patients, home BP readings were the most predictive of ESRD and death [50]. HBPM is useful in CKD patients to predict target organ damage, decline in renal function, CV events, and death.

## Studies in Dialysis

In patients on hemodialysis, a U-shaped curve has been observed with SBP and mortality. Those with the lowest SBP, typically less than 100 mmHg, have the greatest mortality and there is a slight increase in mortality in patients with very high pre or post-dialysis BP readings [51]. Interdialytic BP readings done at home in dialysis patients outside the dialysis unit have been shown to predict target organ damage, including left ventricular hypertrophy (LVH) and mortality [52–57]. In an observational study using HBPM and pre and post-dialysis BP readings [12], weekly averaged BP readings were shown to have a significant correlation with left ventricular

**Table 2.2** Utility of home BP monitoring in CKD patients

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| More accurate assessment of BP in nondialysis CKD and dialysis patients |
| Useful to make medication adjustments |
| Improves BP control |
| Useful to predict: target organ damage, decline in renal function, CV events, and death in nondialysis CKD patients |
| Useful to predict: target organ damage, LVH, left ventricular mass index, CV mortality, and all-cause mortality in dialysis patients |

mass index and PWV, a marker of aortic stiffness, whereas pre-dialysis BP did not show a positive correlation [53]. Pulse pressures derived from within and outside the dialysis clinic, when averaged over a 1-week period have also been shown to be predictive of CV mortality and all-cause mortality [54]. In chronic hemodialysis patients, HBPM has also been shown to have a superior ability to indicate the presence of LVH when compared with pre-dialysis readings [52], and in longitudinal follow-up, patients with elevated home BP readings have higher mortality, whereas dialysis clinic BP readings do not correlate with mortality. HBPM is better correlated than office or clinic BP with target organ damage in CKD and in dialysis patients, and has greater value in predicting CV mortality and all-cause mortality. HBPM can also be incorporated into some electronic health-care records, which holds great potential to improve BP control for patients. HBPM is also attractive because it provides greater patient empowerment in their care, more insight into the connection of BP (and heart rate) with symptoms, and often better control with less medicine and greater attention to lifestyle measures by the patient. Currently, the most important deficit in the home BP initiatives is the lack of outcome data comparing home BP versus clinic BP management. This is an area of extreme need, particularly in dialysis patients. The utility of HBPM in the CKD population is shown in Table 2.2.

## ABPM in CKD

ABPM provides a better measure of BP control when compared to clinic or office BP measurements in the general population and in CKD. An abnormal circadian profile of BP recorded by ABPM measurements is a commonplace in CKD, and the prognostic values of ABPM for predicting renal and CV outcomes are increasingly evident.

## Ambulatory BP Interpretation and Utility in CKD

ABPM is undertaken by wearing a device that takes BP measurements over a 24–48-h period, typically every 15–20 min during the daytime and every 30–60 min during sleep [58]. BP follows an expected circadian variation in most normotensive

and most hypertensive patients, with a decline in BP during sleep. The lowest BP is often at about 3 a.m., followed by a rise during the early hours of the morning before arousal, and the highest BP tend to occur midmorning followed by a progressive fall throughout the day [59, 60]. Using 24-h ABPM, a "dipper" is generally classified as someone whose BP declines by at least 10% or more, when comparing the average daytime with the average nighttime BP values. A blunted circadian variation of BP, termed a "non-dipper," is defined as someone who shows less than the expected 10% decline during the night [61]. CKD is associated with altered circadian BP rhythm, typified by a blunted amplitude of circadian variation as well as increased rates of non-dippers and even some whose BP increases during the night ("reverse dippers," or "risers") [62, 63]. Patietns with essential hypertension have a peak BP in the early afternoon and a nocturnal fall in BP of greater than 10%; however, patients with CKD have a peak BP close to midnight and a mean nocturnal increase in BP. Non-dipper status is more prevalent in patients with CKD compared to patients with essential hypertension [64] and the prevalence of non-dipper status increases progressively as the renal function deteriorates reaching more than 75% in patients with advanced (stage 5) CKD, patients on hemodialysis and peritoneal dialysis, and in renal transplant recipients [64, 65]. There is also a greater prevalence of reverse-dipper status (i.e., nighttime BP rise rather than fall) in CKD versus non-CKD patients [65]. The prevalence of reverse dippers also increases progressively from stage 1 to 5 CKD.

The use of ABPM in CKD demonstrates that approximately 50% of patients have morning hypertension (defined as BP exceeded 135/85 mmHg during the first 2 h after awakening). The majority of these patients with morning hypertension have sustained elevation of nighttime BP (defined as BP > 120/70 mmHg all night) resulting in a high nighttime/daytime BP ratio, suggesting that morning hypertension in CKD is of a sustained type, and not the surge type as reported in other populations [17].

## The Role of ABPM for Predicting CV Risk and CKD Progression

ABPM is an excellent diagnostic tool to diagnose WCH and masked hypertension in CKD. WCH is present in up to about 18% of patients with CKD leading to possible overdiagnosis and overtreatment of hypertension in CKD [66]. Conversely, masked hypertension has been shown to be present in up to 20% of a broad range of patients with CKD [66, 67]. The African–American Study of Kidney Diseases and Hypertension (AASK), focused on one racial cohort, reported a prevalence of masked hypertension in 43% [68]. The failure to identify masked hypertension in CKD leads to undertreatment of hypertension, and may contribute to CKD progression and CV risk. In CKD, as with general hypertensive patients who have normal kidney function, masked hypertension has been associated with the presence of LVH, the degree of proteinuria, and incident CV events [68–70].

**Table 2.3** Utility of ABPM in CKD

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| White coat hypertension |
| Masked hypertension |
| Dipping status (dipping, non-dipping, reverse dipping) |
| Aid in prediction of CV risk |
| Aid in prediction of CKD progression |
| Adjust hypertensive therapy |

Despite many years of availability of ABPM, there are only a few prospective studies in nondialysis CKD patients specifically investigating the prognostic significance of ABP readings for renal and CV outcomes. Data have shown that ABPM is a better tool for predicting renal and CV risk than office-based pressures in patients with various underlying causes of CKD. The predictive power for ABPM to predict renal and CV outcomes is independent of diabetes, proteinuria, level of hemoglobin, and preexisting CVD [71]. Nighttime SBP is a stronger predictor for both renal and CV end points than daytime SBP readings. Nighttime DBP is also a better predictor of fatal and nonfatal CV end points. There is also a twofold increased risk of CV end points in non-dippers and reverse dippers.

ABPM has been compared to office BP in predicting ESRD and death in patients with CKD [49]. ABPM has been shown to be a stronger predictor for ESRD and death than office BP readings and non-dipping is also associated with increased risk of total mortality and ESRD.

The longitudinal prognostic value of ABPM has also been shown using baseline ABPM data, and then assessing the rate of CKD progression and subsequent CV outcomes when evaluated over a 5-year period (70). Results showed that higher 24-h SBP, daytime, nighttime, and clinic SBP were each associated with subsequent renal and CV outcomes. However, after controlling for clinic SBP, baseline ABP readings were predictive of renal outcomes in participants with clinic SBP $< 130$ mmHg and of CV outcomes with no interaction based on clinic BP control.

Combining information using ABPM with eGFR in the prediction of CV outcome has been shown to be superior than using each alone over and adds prognostic value for predicting CKD and CV outcomes [72].

ABPM has also been used to adjust therapy in hypertensive children with CKD [73]. The ESCAPE trial showed that more intense BP control, defined as a mean arterial pressure below the 50th percentile as assessed using ABPM, compared with a target 24-h BP level between the 50th and the 95th percentile resulted in a substantial benefit, i.e., slowing of kidney failure progression among children with CKD. The utility of ABPM in CKD is shown in Table 2.3.

There are several reasons why ABPM provides greater opportunity to profile CV risk and renal disease progression in patients with CKD. It provides many more readings, often more than 50 measurements, compared with a typical office visit of three readings, thereby providing a truer estimate of BP burden on the circulation and the target organs. It captures the pattern of BP over a full

daily cycle and cues the provider into the success, or failure, of BP suppression during the night. In particular, ABPM accurately identifies WCH, which carries less risk than sustained hypertension, and masked hypertension, which carries more risk than normotension. By virtue of the large number of readings, it provides an opportunity to evaluate the variability of BP and heart rate, which have opposing effects on CV outcomes [74]. This information could be used to treat BP in CKD patients more accurately and identify dipping status and aid in stratification of CV risk and risk for CKD progression [75]. The CRIC study will provide more insight into the role of ABPM in CKD patients as it has more than 1500 participants studied with a focus on both CKD progression and CVD outcomes [76]. However, it is important to point out that, as with HBPM, leveraging of the superior capability of ABPM to more accurately profile a patients BP pattern and target organ damage is still largely limited to epidemiologic associations as outcome studies are lacking. This is a challenge and an opportunity for the future.

## Summary

Hypertension is highly prevalent in CKD and use of traditional office or clinic BP measurements has not always correlated well with CKD progression and CV outcomes. The use of the different modalities of BP monitoring described in this chapter all have an increasingly useful role in the diagnosis and management of hypertension in CKD and in particular to aid in prediction of CKD progression and CV risk stratification. HBPM is the easiest modality to incorporate into routine management of hypertension in CKD as it is inexpensive and is associated with improved clinical care and outcomes in both nondialysis CKD patients and dialysis patients. It also directly involves patients in their care and puts some of the responsibility and ownership of improving BP control onto the patient. ABPM is the gold standard of BP measurement but, likely, will continue to be used mostly in selected patients in the clinical setting and in research studies due to the impracticalities associate with its use, including patient burden, costs, and poor reimbursement. Central BP monitoring is a promising modality as it allows arterial stiffness to be measured easily and noninvasively and it is well established that arterial stiffness is an independent predictor of CV events. Once CKD is established, the role of arterial stiffness in the progressive loss of kidney function is less clear. There is much ongoing research in this area, and in the long term, this methodology has the potential to be incorporated into routine clinical decision making when assessing CV risk as more accurate assessment of CV risk will lead to earlier interventions and potentially better outcomes in patients with CKD.

## References


1. Mailloux LU, Levey AS. Hypertension in patients with chronic renal disease. Am J Kidney Dis. 1998;32(5 Suppl 3):S120–41.
2. Kannel WB. Blood pressure as a cardiovascular risk factor: prevention and treatment. JAMA. 1996;275(20):1571–6.
3. O'Rourke MF, Seward JB. Central arterial pressure and arterial pressure pulse: new views entering the second century after Korotkov. Mayo Clin Proc. 2006;81(8):1057–68.
4. Frimodt-Moller M, Nielsen AH, Kamper AL, Strandgaard S. Reproducibility of pulse-wave analysis and pulse-wave velocity determination in chronic kidney disease. Nephrol Dial Transplant. 2008;23(2):594–600.
5. Savage MT, Ferro CJ, Pinder SJ, Tomson CR. Reproducibility of derived central arterial waveforms in patients with chronic renal failure. Clin Sci (Lond). 2002;103(1):59–65.
6. Wimmer NJ, Townsend RR, Joffe MM, Lash JP, Go AS. Chronic renal insufficiency cohort study I: correlation between pulse wave velocity and other measures of arterial stiffness in chronic kidney disease. Clin Nephrol. 2007;68(3):133–43.
7. Williams B, Lacy PS. Central aortic pressure and clinical outcomes. J Hypertens. 2009;27(6):1123–5.
8. Safar ME, Blacher J, Pannier B, Guerin AP, Marchais SJ, Guyonvarc'h PM, et al. Central pulse pressure and mortality in end-stage renal disease. Hypertension. 2002;39(3):735–8.
9. Roman MJ, Devereux RB, Kizer JR, Lee ET, Galloway JM, Ali T, et al. Central pressure more strongly relates to vascular disease and outcome than does brachial pressure: the strong heart study. Hypertension. 2007;50(1):197–203.
10. Pini R, Cavallini MC, Palmieri V, Marchionni N, Di Bari M, Devereux RB, et al. Central but not brachial blood pressure predicts cardiovascular events in an unselected geriatric population: the ICARe Dicomano study. J Am Coll Cardiol. 2008;51(25):2432–9.
11. O'Rourke MF, Adji A. Basis for use of central blood pressure measurement in office clinical practice. J Am Soc Hypertens. 2008;2(1):28–38.
12. DeLoach SS, Townsend RR. Vascular stiffness: its measurement and significance for epidemiologic and outcome studies. Clin J Am Soc Nephrol. 2008;3(1):184–92.
13. Mitchell GF, Parise H, Benjamin EJ, Larson MG, Keyes MJ, Vita JA, et al. Changes in arterial stiffness and wave reflection with advancing age in healthy men and women: the Framingham heart study. Hypertension. 2004;43(6):1239–45.
14. McEniery CM, Yasmin Hall IR, Qasem A, Wilkinson IB, Cockcroft JR. Normal vascular aging: differential effects on wave reflection and aortic pulse wave velocity: the Anglo-Cardiff collaborative trial (ACCT). J Am Coll Cardiol. 2005;46(9):1753–60.
15. Townsend RR, Chirinos JA, Parsa A, Weir MA, Sozio SM, Lash JP, et al. Central pulse pressure in chronic kidney disease: a chronic renal insufficiency cohort ancillary study. Hypertension. 2010;56(3):518–24.
16. DeLoach SS, Appel LJ, Chen J, Joffe MM, Gadegbeku CA, Mohler ER 3rd, et al. Aortic pulse pressure is associated with carotid IMT in chronic kidney disease: report from chronic renal insufficiency cohort. Am J Hypertens. 2009;22(12):1235–41.
17. Laurent S, Cockcroft J, Van Bortel L, Boutouyrie P, Giannattasio C, Hayoz D, et al. Expert consensus document on arterial stiffness: methodological issues and clinical applications. Eur Heart J. 2006;27(21):2588–605.
18. Franklin SS, Gustin Wt, Wong ND, Larson MG, Weber MA, Kannel WB, et al. Hemodynamic patterns of age-related changes in blood pressure: the Framingham heart study. Circulation. 1997;96(1):308–15.
19. Izzo JL Jr. Arterial stiffness and the systolic hypertension syndrome. Curr Opin Cardiol. 2004;19(4):341–52.
20. Safar ME, Thomas F, Blacher J, Nzietchueng R, Bureau JM, Pannier B, et al. Metabolic syndrome and age-related progression of aortic stiffness. J Am Coll Cardiol. 2006;47(1):72–5.
21. Zhang M, Bai Y, Ye P, Luo L, Xiao W, Wu H, et al. Type 2 diabetes is associated with increased pulse wave velocity measured at different sites of the arterial system but not augmentation index in a Chinese population. Clin Cardiol. 2011;34(10):622–7.

22. Lukich E, Matas Z, Boaz M, Shargorodsky M. Increasing derangement of glucose homeostasis is associated with increased arterial stiffness in patients with diabetes, impaired fasting glucose and normal controls. Diabetes Metab Res Rev. 2010;26(5):365–70.
23. Upadhyay A, Hwang SJ, Mitchell GF, Vasan RS, Vita JA, Stantchev PI, et al. Arterial stiffness in mild-to-moderate CKD. J Am Soc Nephrol. 2009;20(9):2044–53.
24. London G, Guerin A, Pannier B, Marchais S, Benetos A, Safar M. Increased systolic pressure in chronic uremia: role of arterial wave reflections. Hypertension. 1992;20(1):10–9.
25. Townsend RR, Wimmer NJ, Chirinos JA, Parsa A, Weir M, Perumal K, et al. Aortic PWV in chronic kidney disease: a CRIC ancillary study. Am J Hypertens. 2010;23(3):282–9.
26. Blacher J, Guerin AP, Pannier B, Marchais SJ, Safar ME, London GM. Impact of aortic stiffness on survival in end-stage renal disease. Circulation. 1999;99(18):2434–9.
27. Pannier B, Guerin AP, Marchais SJ, Safar ME, London GM. Stiffness of capacitive and conduit arteries: prognostic significance for end-stage renal disease patients. Hypertension. 2005;45(4):592–6.
28. London GM, Blacher J, Pannier B, Guerin AP, Marchais SJ, Safar ME. Arterial wave reflections and survival in end-stage renal failure. Hypertension. 2001;38(3):434–8.
29. Covic A, Mardare N, Gusbeth-Tatomir P, Prisada O, Sascau R, Goldsmith DJ. Arterial wave reflections and mortality in haemodialysis patients-only relevant in elderly, cardiovascularly compromised? Nephrol Dial Transplant. 2006;21(10):2859–66.
30. Ng KP, Moody WE, Chue CD, Edwards NC, Savage T, Tomson CR, et al. Central pulse pressure in patients with chronic kidney disease and in renal transplant recipients. J Hum Hypertens. 2013;28:180–5.
31. Takenaka T, Mimura T, Kanno Y, Suzuki H. Qualification of arterial stiffness as a risk factor to the progression of chronic kidney diseases. Am J Nephrol. 2005;25(5):417–24.
32. Taal MW, Sigrist MK, Fakis A, Fluck RJ, McIntyre CW. Markers of arterial stiffness are risk factors for progression to end-stage renal disease among patients with chronic kidney disease stages 4 and 5. Nephron Clin Pract. 2007;107(4):c177–81.
33. Weir MR, Townsend RR, Fink JC, Teal V, Anderson C, Appel L, et al. Hemodynamic correlates of proteinuria in chronic kidney disease. Clin J Am Soc Nephrol. 2011;6(10):2403–10.
34. Ignace S, Utescu MS, De Serres SA, Marquis K, Gaudreault-Tremblay MM, Lariviere R, et al. Age-related and blood pressure-independent reduction in aortic stiffness after kidney transplantation. J Hypertens. 2011;29(1):130–6.
35. Andersen MJ, Khawandi W, Agarwal R. Home blood pressure monitoring in CKD. Am J Kidney Dis. 2005;45(6):994–1001.
36. Agarwal R. Managing hypertension using home blood pressure monitoring among haemodialysis patients-a call to action. Nephrol Dial Transplant. 2010;25(6):1766–71.
37. Agarwal R, Satyan S, Alborzi P, Light RP, Tegegne GG, Mazengia HS, et al. Home blood pressure measurements for managing hypertension in hemodialysis patients. Am J Nephrol. 2009;30(2):126–34.
38. Deziel C, Bouchard J, Zellweger M, Madore F. Impact of hemocontrol on hypertension, nursing interventions, and quality of life: a randomized, controlled trial. Clin J Am Soc Nephrol. 2007;2(4):661–8.
39. da Silva GV, de Barros S, Abensur H, Ortega KC, Mion D Jr. Home blood pressure monitoring in blood pressure control among haemodialysis patients: an open randomized clinical trial. Nephrol Dial Transplant. 2009;24(12):3805–11.
40. Kauric-Klein Z, Artinian N. Improving blood pressure control in hypertensive hemodialysis patients. CANNT J. 2007;17(4):24–8, 31–6; quiz 29–30, 7–8.
41. Agarwal R, Light RP. Chronobiology of arterial hypertension in hemodialysis patients: implications for home blood pressure monitoring. Am J Kidney Dis. 2009;54(4):693–701.
42. Mitra S, Chandna SM, Farrington K. What is hypertension in chronic haemodialysis? The role of interdialytic blood pressure monitoring. Nephrol Dial Transplant. 1999;14(12):2915–21.
43. Agarwal R, Andersen MJ, Light RP. Location not quantity of blood pressure measurements predicts mortality in hemodialysis patients. Am J Nephrol. 2008;28(2):210–7.
44. Wang MC, Tseng CC, Tsai WC, Huang JJ. Blood pressure and left ventricular hypertrophy in patients on different peritoneal dialysis regimens. Perit Dial Int. 2001;21(1):36–42.

45. Agarwal R. Home and ambulatory blood pressure monitoring in chronic kidney disease. Curr Opin Nephrol Hypertens. 2009;18(6):507–12.
46. Rave K, Bender R, Heise T, Sawicki PT. Value of blood pressure self-monitoring as a predictor of progression of diabetic nephropathy. J Hypertens. 1999;17(5):597–601.
47. Suzuki H, Nakamoto H, Okada H, Sugahara S, Kanno Y. Self-measured systolic blood pressure in the morning is a strong indicator of decline of renal function in hypertensive patients with non-diabetic chronic renal insufficiency. Clin Exp Hypertens. 2002;24(4):249–60.
48. Okada T, Nakao T, Matsumoto H, Nagaoka Y, Tomaru R, Iwasawa H, et al. Prognostic significance of home blood pressure control on renal and cardiovascular outcomes in elderly patients with chronic kidney disease. Hypertens Res. 2009;32(12):1123–9.
49. Agarwal R, Andersen MJ. Prognostic importance of ambulatory blood pressure recordings in patients with chronic kidney disease. Kidney Int. 2006;69(7):1175–80.
50. Agarwal R, Andersen MJ. Prognostic importance of clinic and home blood pressure recordings in patients with chronic kidney disease. Kidney Int. 2006;69(2):406–11.
51. Agarwal R. Hypertension and survival in chronic hemodialysis patients-past lessons and future opportunities. Kidney Int. 2005;67(1):1–13.
52. Agarwal R, Brim NJ, Mahenthiran J, Andersen MJ, Saha C. Out-of-hemodialysis-unit blood pressure is a superior determinant of left ventricular hypertrophy. Hypertension. 2006;47(1):62–8.
53. Moriya H, Ohtake T, Kobayashi S. Aortic stiffness, left ventricular hypertrophy and weekly averaged blood pressure (WAB) in patients on haemodialysis. Nephrol Dial Transplant. 2007;22(4):1198–204.
54. Moriya H, Oka M, Maesato K, Mano T, Ikee R, Ohtake T, et al. Weekly averaged blood pressure is more important than a single-point blood pressure measurement in the risk stratification of dialysis patients. Clin J Am Soc Nephrol. 2008;3(2):416–22.
55. Amar J, Vernier I, Rossignol E, Bongard V, Arnaud C, Conte JJ, et al. Nocturnal blood pressure and 24-hour pulse pressure are potent indicators of mortality in hemodialysis patients. Kidney Int. 2000;57(6):2485–91.
56. Alborzi P, Patel N, Agarwal R. Home blood pressures are of greater prognostic value than hemodialysis unit recordings. Clin J Am Soc Nephrol. 2007;2(6):1228–34.
57. Agarwal R. Hypervolemia is associated with increased mortality among hemodialysis patients. Hypertension. 2010;56(3):512–7.
58. Pickering TG, Miller NH, Ogedegbe G, Krakoff LR, Artinian NT, Goff D. Call to action on use and reimbursement for home blood pressure monitoring: executive summary: a joint scientific statement from the American Heart Association, American Society Of Hypertension, and Preventive Cardiovascular Nurses Association. Hypertension. 2008;52(1):1–9.
59. Millar-Craig MW, Bishop CN, Raftery EB. Circadian variation of blood-pressure. Lancet. 1978;1(8068):795–7.
60. Pickering TG, Harshfield GA, Kleinert HD, Blank S, Laragh JH. Blood pressure during normal daily activities, sleep, and exercise. Comparison of values in normal and hypertensive subjects. JAMA. 1982;247(7):992–6.
61. O'Brien E, Sheridan J, O'Malley K. Dippers and non-dippers. Lancet. 1988;2(8607):397.
62. Portaluppi F, Montanari L, Ferlini M, Gilli P. Altered circadian rhythms of blood pressure and heart rate in non-hemodialysis chronic renal failure. Chronobiol Int. 1990;7(4):321–7.
63. Portaluppi F, Montanari L, Massari M, Di Chiara V, Capanna M. Loss of nocturnal decline of blood pressure in hypertension due to chronic renal failure. Am J Hypertens. 1991;4(1 Pt 1):20–6.
64. Farmer CK, Goldsmith DJ, Cox J, Dallyn P, Kingswood JC, Sharpstone P. An investigation of the effect of advancing uraemia, renal replacement therapy and renal transplantation on blood pressure diurnal variability. Nephrol Dial Transplant. 1997;12(11):2301–7.
65. Mojon A, Ayala DE, Pineiro L, Otero A, Crespo JJ, Moya A, et al. Comparison of ambulatory blood pressure parameters of hypertensive patients with and without chronic kidney disease. Chronobiol Int. 2013;30(1/2):145–58.

66. Bangash F, Agarwal R. Masked hypertension and white-coat hypertension in chronic kidney disease: a meta-analysis. Clin J Am Soc Nephrol. 2009;4(3):656–64.
67. Bobrie G, Clerson P, Menard J, Postel-Vinay N, Chatellier G, Plouin PF. Masked hypertension: a systematic review. J Hypertens. 2008;26(9):1715–25.
68. Pogue V, Rahman M, Lipkowitz M, Toto R, Miller E, Faulkner M, et al. Disparate estimates of hypertension control from ambulatory and clinic blood pressure measurements in hypertensive kidney disease. Hypertension. 2009;53(1):20–7.
69. Minutolo R, Borrelli S, Scigliano R, Bellizzi V, Chiodini P, Cianciaruso B, et al. Prevalence and clinical correlates of white coat hypertension in chronic kidney disease. Nephrol Dial Transplant. 2007;22(8):2217–23.
70. Gabbai FB, Rahman M, Hu B, Appel LJ, Charleston J, Contreras G, et al. Relationship between ambulatory BP and clinical outcomes in patients with hypertensive CKD. Clin J Am Soc Nephrol. 2012;7(11):1770–6.
71. Minutolo R, Agarwal R, Borrelli S, Chiodini P, Bellizzi V, Nappi F, et al. Prognostic role of ambulatory blood pressure measurement in patients with nondialysis chronic kidney disease. Arch Intern Med. 2011;171(12):1090–8.
72. Boggia J, Thijs L, Li Y, Hansen TW, Kikuya M, Bjorklund-Bodegard K, et al. Risk stratification by 24-hour ambulatory blood pressure and estimated glomerular filtration rate in 5322 subjects from 11 populations. Hypertension. 2013;61(1):18–26.
73. Wuhl E, Trivelli A, Picca S, Litwin M, Peco-Antic A, Zurowska A, et al. Strict blood-pressure control and progression of renal failure in children. N Engl J Med. 2009;361(17):1639–50.
74. Rubin MF, Brunelli SM, Townsend RR. Variability-the drama of the circulation. J Clin Hypertens (Greenwich). 2010;12(4):284–7.
75. Clement DL, De Buyzere ML, De Bacquer DA, de Leeuw PW, Duprez DA, Fagard RH, et al. Prognostic value of ambulatory blood-pressure recordings in patients with treated hypertension. N Engl J Med. 2003;348(24):2407–15.
76. Feldman HI, Appel LJ, Chertow GM, Cifelli D, Cizman B, Daugirdas J, et al. The chronic renal insufficiency cohort (CRIC) study: design and methods. J Am Soc Nephrol. 2003;14(7 Suppl 2):S148–53.