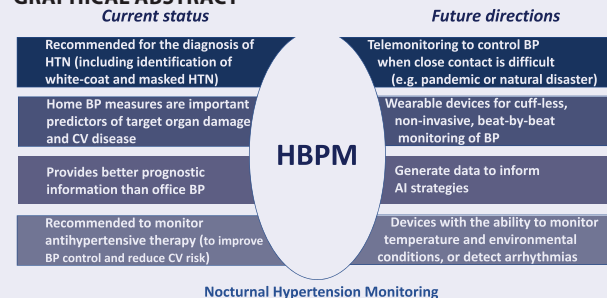# Home Blood Pressure Monitoring: Current Status and New Developments

Kazuomi Kario[1,2,]

Home blood pressure monitoring (HBPM) is a reliable, convenient, and less costly alternative to ambulatory blood pressure monitoring (ABPM) for the diagnosis and management of hypertension. Recognition and use of HBPM have dramatically increased over the last 20 years and current guidelines make strong recommendations for the use of both HBPM and ABPM in patients with hypertension. The accuracy and reliability of home blood pressure (BP) measurements require use of a validated device and standardized procedures, and good patient information and training. Key HBPM parameters include morning BP, evening BP, and the morning–evening difference. In addition, newer semi-automatic HBPM devices can also measure nighttime BP at fixed intervals during sleep. Advances in technology mean that HBPM devices could provide additional relevant data (e.g., environmental conditions) or determine BP in response to a specific trigger (e.g., hypoxia, increased heart rate). The value of HBPM is highlighted by a growing body of evidence showing that home BP is an important predictor of target organ damage, and cardiovascular disease (CVD)- and stroke-related morbidity and mortality, and provides better prognostic information than office BP. In addition, use of HBPM to monitor antihypertensive therapy can help to optimize reductions in BP, improve BP control, and reduce target organ damage and cardiovascular risk. Overall, HBPM should play a central role in the management of patients with hypertension, with the goal of identifying increased risk and predicting the onset of CVD events, allowing proactive interventions to reduce risk and eliminate adverse outcomes.

GRAPHICAL ABSTRACT

AI, artificial intelligence BP, blood pressure; CV, cardiovascular; HBPM, home blood pressure monitoring; HTN, hypertension.

HISTORY AND GUIDELINES

Home blood pressure monitoring (HBPM) uses similar technology to ambulatory blood pressure monitoring (ABPM), but allows patients to perform their own blood pressure (BP) measurements at a time and frequency that suits them. HBPM provides information on BP at specific times and under everyday conditions over long time periods. Key advantages of HBPM include its relatively widespread availability, the ability to take multiple daily readings over a long period of time, avoidance of white-coat reactions, the ability to detect masked hypertension and BP variability, improved management of hypertension due to immediate feedback and patient involvement in their healthcare, and relatively low cost.[1–3] Disadvantages include the requirement for patient education and training, measurement errors, and lack of funding in some healthcare settings.[1]

Although ABPM is the gold standard out-of-office BP measurement, HBPM is recommended as a more practical and less expensive alternative, especially for long-term monitoring of treated patients with hypertension.[4,5] Recognition and use of HBPM have increased dramatically

Correspondence: Kazuomi Kario (kkario@jichi.ac.jp).

[1]**Division of Cardiovascular Medicine, Department of Medicine, Jichi Medical University School of Medicine, Shimotsuke, Tochigi, Japan; [2]The Hypertension Cardiovascular Outcome Prevention and Evidence in Asia (HOPE Asia) Network, Tokyo, Japan.**

Table 1. Home blood pressure monitoring recommendations in major guideline and consensus documents

	Diagnosis of hypertension	Diagnostic BP threshold, mm Hg	Titration and monitoring of antihypertensive therapy	Target BP threshold, mm Hg
ACC/AHA 2017[9]	✓	≥130/80	✓	<130/80
ESC/ESH 2018[10]	✓	≥135/85	✓	≤130/80
ISH 2020[8]	✓	≥135/85	✓	<135/85
JSH 2019[7]	✓	≥135/85	✓	<125/75 (age <75 y) or <135/85 (age ≥75 y)
China 2019[11]	✓	≥135/85	✓	<140/90 or <130/80 if tolerated or in high-risk pts
Taiwan 2015[12]	✓	≥135/85	✓	<140/90 or <130/80 if tolerated or in high-risk pts
South Korea 2018[13]	✓	≥135/85	✓	<140/90 (uncomplicated/elderly) or <130/80 (high-risk pts)
HOPE Asia Network[14]	✓	≥135/85	✓	<135/85

Abbreviations: pts, patients; y, years.

over the last 20 years.[6] Current hypertension guideline documents make strong recommendations for the use of out-of-office BP monitoring techniques, including HBPM and ABPM, for the diagnosis of hypertension and for the monitoring and management of antihypertensive therapy (Table 1).[1,7–10]

Patients for whom out-of-office BP monitoring with HBPM is indicated include those with high office BP (to detect white-coat hypertension), high-normal office BP or normal office BP with hypertension-mediated organ damage or high cardiovascular (CV) risk (to detect masked hypertension), highly variable office BP or resistant hypertension, and for evaluating BP control (especially in high-risk patients).[8,10,15] The Japanese guidelines state that where there is a discrepancy between office BP and home BP readings, a home BP-based diagnosis should take precedence.[7]

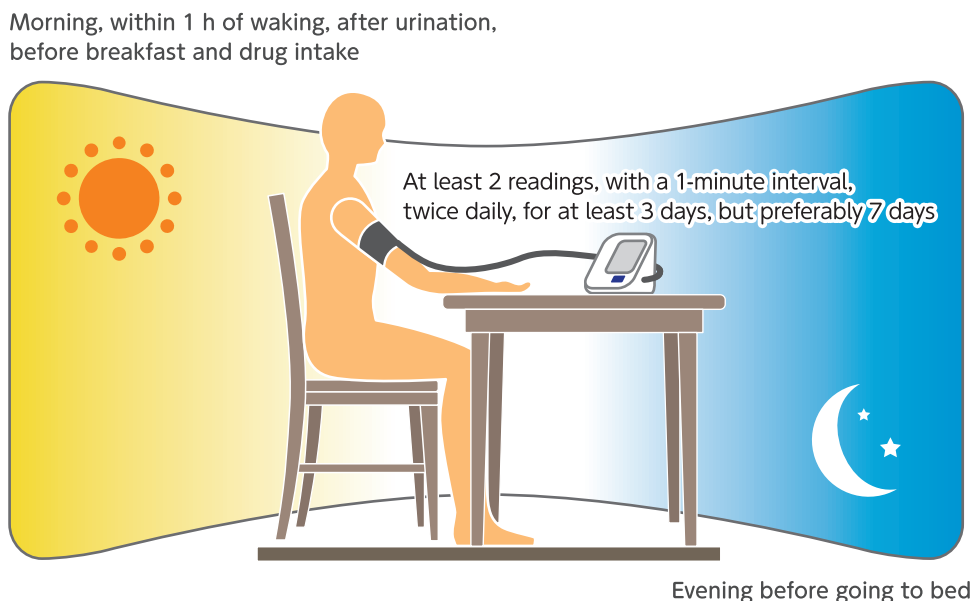## HOME BP MEASUREMENT: SCHEDULE, THRESHOLDS, AND APPROACHES

Good patient information and training, use of standardized procedures and use of a validated device are essential for ensuring the accuracy and reliability of home BP measurements (Figure 1).[16] Patients need to be provided with general information about hypertension diagnosis and treatment, along with guidance on how to select an appropriate HBPM device and how to measure their own BP (ideally accompanied by a hands-on demonstration).[1,5,16] It is important to remind patients not to overuse HBPM and not to modify their antihypertensive therapy without consulting their physician.[1] In addition to being validated, the HBPM device should use an upper-arm cuff oscillometric method (with an appropriately sized cuff) and be able to automatically store all readings; telehealth-equipped devices that can transmit readings to healthcare providers are preferable.[1,5,16,17] The patient should have an empty bladder, and rest quietly in a seated position with the back supported and both feet on the floor for 2–5 minutes before taking home BP measurements. The cuff of the device should be

placed directly above the elbow and pulled taut, with the arm supported on a flat surface. Morning measurements should be made before breakfast and before taking any antihypertensive drugs, and evening measurements should be taken before going to bed. At least 2 readings should be taken, 1–2 minutes apart, and measurements should be made for at least 3 (preferably 7) consecutive days.[1,14,16,18]

The key parameters provided by HBPM include morning BP, evening BP, and the morning–evening difference in BP. The relationship between values for these home BP measures and office BP is shown in Table 2. However, 1 limitation of standard HBPM is that measurements are only taken at 2 times during the day (morning and evening) in a relatively low-stress environment (i.e., the patient's home). Given that young adult workers often show increased work site BP, especially during stressful conditions, even when home BP is well controlled,[19,20] there may be also a role for HBPM in the work place.

Although morning and evening BP are important from a prognostic perspective (see below), information on BP during everyday activities, such as work, and overnight is also helpful. Determination of BP during physical activity or home- or work-related psychological stress would require complementary use of ABPM, but semi-automatic HBPM devices are now available that measure BP at fixed intervals during sleep. These have been used successfully to monitor nighttime BP in a number of clinical trials.[21–26] A 2-night schedule with 6 readings per night appears to be the minimum requirement for reliable assessment of nighttime home BP. This showed reasonable agreements with ABPM and acceptable associations with markers of preclinical organ damage.[27] The reliability of nocturnal HBPM appeared to be similar when HBPM was performed at intervals based on bedtime (e.g., 2, 3, or 4 hours after a chosen bedtime) or when fixed times were chosen (e.g., 2 AM, 3 AM, and 4 AM).[28]

More sophisticated devices can monitor temperature as well as BP, providing data on potential factors associated with changes in BP, including environmental factors such ambient temperature (Figure 2). These devices were used in clinical

Morning, within 1 h of waking, after urination, before breakfast and drug intake

At least 2 readings, with a 1-minute interval, twice daily, for at least 3 days, but preferably 7 days

Evening before going to bed

Figure 1. Key recommendations for ensuring accurate measurement of home blood pressure.[14,16,18]

Table 2. Home blood pressure (BP) values (mm Hg) corresponding to clinic measurements (reproduced, with permission, from Kario *et al.*)[14]

Clinic BP (mm Hg)	Home BP (mm Hg)			
	Morning	Evening	Nighttime	ME average
120/80	120/80	120/80	100/65	120/80
130/80	130/80	130/80	110/65	130/80
140/90[a]	135/85[a]	135/85[a]	120/70[a]	135/85[a]
160/100	145/90	145/90	140/85	145/90

Abbreviation: ME average, average of morning and evening BP values.
[a]Pathologic threshold.

trials enrolling patients with uncontrolled nocturnal hypertension,[29,30] and may also have potential applications in clinical practice. Other approaches that allow assessment of nighttime BP include "trigger nighttime HBPM" where BP measurement is triggered by an episode of hypoxia or an elevation in heart rate, and beat-by-beat continuous surge BP monitoring.[31,32] Combining individual time-series data with environmental factors is another novel approach to HBPM, which facilitates a more holistic approach to the measurement and management of BP.[33] Technological advances such as these will increase the applicability and usefulness of HBPM for a range of different hypertension patient phenotypes.

PROGNOSTIC VALUE OF HBPM

The value of HBPM is highlighted by data from multiple studies showing that home BP is an important predictor of target organ damage, and cardiovascular disease (CVD)- and stroke-related morbidity and mortality, and provides better prognostic information than office BP.[35–41] Of these,

the first study to show that home BP was a better predictor of mortality than screening office BP was the Ohasama study, conducted in a general population in Japan.[40] The HONEST study also provides evidence that morning hypertension determined using HBPM is superior to office BP measurements for predicting the future occurrence of CV events.[42,43] Furthermore, HBPM parameters have been shown to improve CV risk stratification in untreated patients with hypertension.[44]

An overview of studies investigating the link between HBPM parameters and target organ damage/CV risk is provided in Table 3. In addition, the sections below provide specific information relating to each key HBPM parameter.

Morning home BP

Even when office BP is normal, patients with masked hypertension and high morning systolic BP (SBP) have a high risk of CV events.[42] When detected by HBPM or ABPM, the presence of masked hypertension and masked uncontrolled
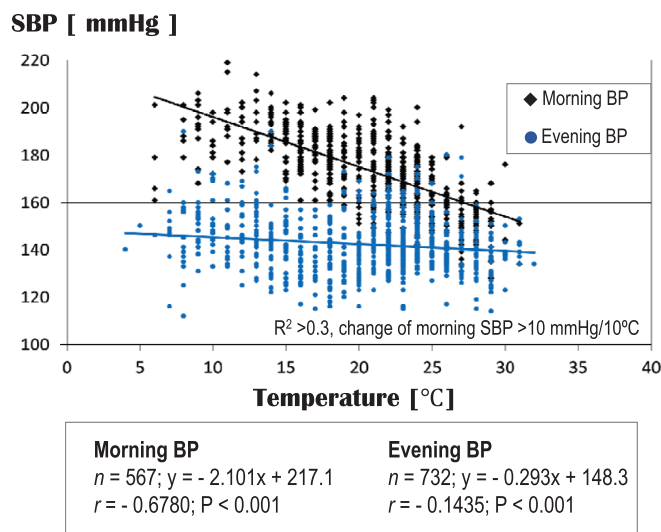
Figure 2. Thermosensitive morning hypertension documented using a home blood pressure (BP) monitoring device including a temperature sensor. Left: A case of thermosensitive hypertension [Measured from March 7, 2015 to December 18, 2015] (reproduced, with permission, from Kario).[34]

hypertension is associated with poor clinical outcomes.[54] Morning home SBP ≥155 mm Hg has been shown to increase the risk of developing coronary artery disease by more than 6-fold, almost twice the risk associated with office SBP ≥160 mm Hg.[43] Morning home BP has also been shown to have better reproducibility than ambulatory BP measurements, and a stronger correlation with indices of vascular function.[55] Furthermore, morning home SBP improves the discrimination of incident stroke over and above traditional risk factors (including office BP) and was a better predictor of stroke risk than evening home BP (Figure 3).[50] This suggests that morning home SBP should be monitored and controlled to ensure optimal protection against CVD and stroke in clinical practice. Guideline recommendations note that morning home BP should be measured prior to antihypertensive drug dosing.[7,9,10]

Nighttime home BP

Control of nocturnal BP is also an important part of CV risk management strategies,[34,56] and nocturnal hypertension is common in hypertensive patients with comorbidities such as diabetes mellitus, chronic kidney disease, or obstructive sleep apnea. Until relatively recently, the only option for measuring nighttime BP was ABPM. However, new HBPM devices have been developed that provide another option for nighttime BP measurement.[32,57] These have been shown to provide similar BP values to ABPM, and similar associations with target organ damage.[58]

One of the first studies to highlight the importance of nighttime BP was the Ohasama study, which showed that nighttime BP had a better prognostic value than daytime BP.[59] In a Cox model including both nighttime and daytime SBP, only nighttime BP was a significant predictor of CV mortality risk over 10.8 years of follow-up.[59] Another recent study also documented the importance of nighttime BP levels and a riser pattern of nighttime BP, both of which were independently associated with the total CV event rate.[60] In the J-HOP study, home sleep
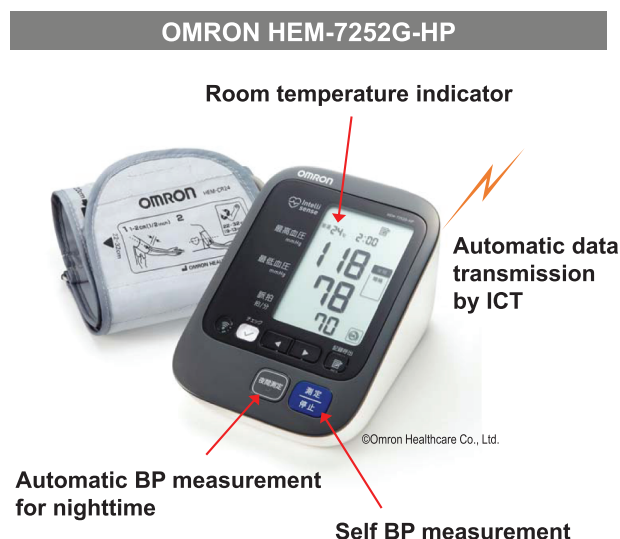
SBP values were correlated with several manifestations of CV target organ damage, including the left ventricular mass index, urinary albumin–creatinine ratio, arterial stiffness parameters, amino terminal pro B-type natriuretic peptide levels, and these associations persisted after adjustment for clinic SBP and morning and evening home SBP.[22,24] Furthermore, the J-HOP Nocturnal BP study identified a significant increase in CV risk with each 10-mm Hg increase in nighttime home SBP.[26] In addition, the CV event risk associated with masked nocturnal hypertension was nearly as high as that associated with sustained hypertension (Figure 4).[52]

Recent data highlight the importance of nocturnal hypertension measured using HBPM rather than ABPM. Data from the J-HOP study were used to compare the prognostic power of nocturnal hypertension detected by HBPM vs. ABPM for predicting future CV events.[53] Home nighttime SBP was significantly higher than ambulatory nighttime SBP (123.0 ± 14.6 vs. 120.3 ± 14.4 mm Hg, $P < 0.001$). In addition, nocturnal hypertension detected using HBPM (home SBP >120 mm Hg) was significantly associated with an increased risk of future CV events, independent of office SBP (hazard ratio [95% confidence interval] for CAD + stroke, 1.78 [1.00–3.15] and for stroke only, 2.65 [1.14–6.20]), whereas no such association was seen for nocturnal hypertension defined and detected using ABPM (Figure 5).[53]

Home BP variability

There are a variety of ways that BP variability can be defined, including beat-by-beat, daily, seasonal, and long term. Morning, evening, and nocturnal hypertension, the morning BP surge and nocturnal dipping are all examples of circadian variation in BP. There is good agreement between HBPM and ABPM for detection of patients with a nondipping nocturnal BP profile.[61] HBPM can also be used to detect long-term and seasonal variations in BP.[19,62–65] Seasonal- and temperature-related variations in BP could become increasingly relevant

Table 3. Prospective studies investigating the relationship between home blood pressure monitoring parameters and the occurrence of cardiovascular events

Study	Design and location	Population and follow-up	Outcomes
Ohasama study Ohkubo et al.[40]	Prospective cohort study (Japan)	N = 1,789 (age ≥40 y) Mean FU 6.6 y	Relative HR (95% CI) for CV mortality associated with a 1-mm Hg increase in home BP was 1.021 (1.001–1.041; $P < 0.05$)
Kahoku-chyo study Okumiya et al.[45]	Prospective cohort study (Japan)	N = 1,186 (mean age 73.5 y) 4-y FU	Adjusted HR (95% CI) values for CV mortality associated with home SBP ≥135–144 and ≥145 mm Hg vs. 125–134 mm Hg (reference) were 2.3 (1.0–5.6; $P < 0.05$) and 2.1 (0.9–5.0; $P < 0.1$), respectively
Tsunoda et al.[36]	Longitudinal, cross-sectional study (Japan)	N = 209 (age 31–86 y) 5-y FU	Home BP was more closely related to target organ damage (especially LVMI) than office BP
SHEAF study Bobrie et al.[37]	Prospective cohort study (France)	N = 4,939 (mean age 70 ± 6.5 y) Mean FU 3.2 y	In treated pts with HTN, each 10-mm Hg increase in home SBP increased CV event risk by 17.2% (95% CI 11.0–23.8%) and each 5-mm Hg increase in home DBP increased CV event risk by 11.7% (95% CI 5.7–18.1%); similar increases in office BP were not associated with a significant increase in CV event risk
Ohasama study Asayama et al.[46]	Prospective cohort study (Japan)	N = 1,702 (age ≥40 y) Mean FU 11 y	Home BP-based JNC-7 classification was a stronger predictor of stroke risk than clinic BP-based classification
PAMELA study Sega et al.[47]	Prospective cohort study (Italy)	N = 2,051 (age 25–74 y) Mean FU 131 months	Office, home, and ambulatory BP values showed a significant exponential direct relationship with risk of CV or all-cause death, greater for SBP vs. DBP and for nighttime BP vs. daytime BP, but not better for home or ambulatory vs. office BP; however, the slope of the relationship was progressively greater from office to home and ambulatory BP. The HR for CV mortality with a 1-mm Hg increase in BP was 1.05 (95% CI 1.04–1.06; $P < 0.0001$)[a]
Fagard et al.[38]	Prospective cohort study (Belgium)	N = 391 (mean age 71 y) Mean FU 10.9 y	Adjusted relative HR for CV events associated with a 1 SD increase in home BP (22.9 mm Hg) was 1.32 (95% CI 1.06–1.64; $P = 0.01$); the prognostic value of home BP was better than that of office BP
Shimbo et al.[35]	Prospective cohort study (United States)	N = 163 (mean age 53.9 ± 14.5 y) 10-Week FU	In a multivariate regression analysis including age, sex, BMI, office BP, awake ambulatory BP and home BP, only age, sex, and home BP were significant predictors of LVMI
Niiranen et al.[39]	Prospective cohort study (Finland)	N = 2,081 (age 45–74 y) Median FU 6.8 y	Home SBP/DBP (HR 1.22/1.15, 95% CI 1.09–1.37/1.05–1.26), but not office SBP/DBP (HR 1.01/1.06, 95% CI 0.92–1.12/0.97–1.16), was a significant predictor of CV events; the only significant predictor of total mortality was home SBP (HR 1.11, 95% CI 1.01–1.23)
HOMED-BP study Asayama et al.[48]	Randomized intervention study (Japan)	N = 3,518 (mean age 59.6 y) Median FU 5.3 y	Adjusted HR (95% CI) for fatal or nonfatal CV events associated with a 1 SD (13.2 mm Hg) increase in home BP was 1.47 (1.23–1.75, $P < 0.0001$), irrespective of the antihypertensive used
J-HOP study Ishikawa et al.[22]	Prospective observational study (Japan)	N = 854 (mean 63.0 ± 10.6 y) Mean FU 4 y	Nighttime home SBP was more strongly related to the UACR and LVMI than nighttime ambulatory SBP ($P < 0.001$ for difference)
J-HOP study Kario et al.[24]	Prospective observational study (Japan)	N = 2,562 (mean 64.8 ± 10.9 y) Mean FU 4 y	Home sleep SBP values were correlated with markers of target organ damage (UACR, LVMI, baPWV, maximum carotid IMT, and plasma NT-proBNP levels (all $P < 0.001$); the associations between home sleep SBP and UACR, LVMI and baPWV remained significant after controlling for clinic SBP and home morning and evening SBPs (all $P < 0.008$)
Dallas Heart study Tientcheu et al.[49]	Prospective cohort study (United States)	N = 3,027 (age 18–65 y) Median FU 9 y	Adjusted HR (95% CI) for the risk of composite CV events in pts with masked hypertension diagnosed using HBPM vs. normotensive pts was 2.03 (1.36–3.03; $P = 0.0005$)
J-HOP study Hoshide et al.[50]	Prospective observational study (Japan)	N = 4,310 (mean age 65 y) Mean FU 4 y	Adjusted HR (95% CI) for the occurrence of stroke with each 10-mm Hg increase in home BP was 1.36 (1.19–1.56; $P < 0.001$) Morning home SBP improved the discrimination of incident stroke beyond traditional risk factors, including office BP

Table 3. Continued

Study	Design and location	Population and follow-up	Outcomes
Didima study Ntineri et al.[51]	Cross-sectional population study (Greece)	N = 694 (mean age 54.4 ± 17.7 y) Mean FU 19.1 ± 1.4 y	Home BP was not a significant predictor of CVD events after adjustment for baseline risk factors Home SBP variability was a significant independent predictor of total mortality (adjusted HR 1.18 [95% CI 1.03–1.36] per 1 SD increase; $P < 0.05$)
J-HOP Nocturnal BP study Kario et al.[26]	Prospective cohort study (Japan)	N = 2,547 (mean age 63 ± 10.4 y) Mean FU 7.1 ± 3.8 y	Adjusted HR (95% CI) for CV events with a 10-mm Hg increase in nighttime home SBP was 1.201 (1.046–1.378)
J-HOP Nocturnal BP study Fujiwara et al.[52]	Prospective cohort study (Japan)	N = 2,547 (mean age 63 ± 10.4 y) Mean FU 7.1 ± 3.8 y	The cumulative incidence of CVD events was higher in pts with masked nocturnal HTN and sustained HTN (both based on HBPM) than in those with controlled BP Masked nocturnal HTN (adjusted HR [95% CI] 1.57 [1.00–2.46]) and sustained HTN (1.97 [1.263.06]) were associated with an increased risk of CVD events
J-HOP study Mokwatsi et al.[53]	Prospective observational study (Japan)	N = 1,005 (mean age 63.2 ± 10.8 y) Mean FU 7.6 ± 3.4 y	Adjusted HR (95% CI) for the risk of total CVD events (CAD + stroke) was 1.78 (1.00–3.15; $P < 0.01$) for HBPM-defined nocturnal HTN and 1.24 (0.75–2.06) for ABPM-defined nocturnal HTN Adjusted HR (95% CI) for the risk of stroke was 2.65 (1.14–6.20; $P < 0.05$) for HBPM-defined nocturnal HTN and 1.08 (0.55–2.15) for ABPM-defined nocturnal HTN

Abbreviations: APBM, ambulatory blood pressure monitoring; baPWV, brachial-ankle pulse wave velocity; BMI, body mass index; BP, blood pressure; CAD, coronary artery disease; CI, confidence interval; CV, cardiovascular; CVD, cardiovascular disease; DBP, diastolic BP; FU, follow-up; HBPM, home blood pressure monitoring; HF, heart failure; HR, hazard ratio; HTN, hypertension; IMT, intima–media thickness; JNC-7, Seventh Joint National Committee; LVMI, left ventricular mass index; MH, masked hypertension; NT-proBNP, amino terminal pro B-type natriuretic peptide; SBP, systolic blood pressure; UACR, urinary albumin–creatinine ratio; y, years.

aCalculated from presented data of beta coefficient and SE in this study.
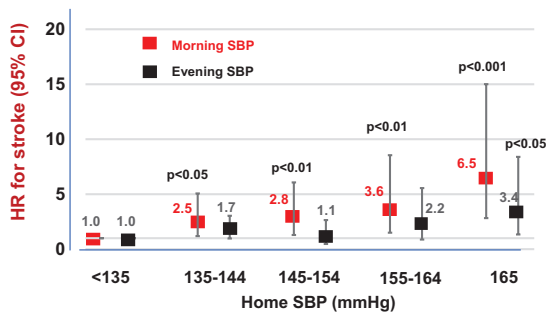
Event number/total number

Morning	12/1958	20/1044	16/687	11/342	15/247
Evening	35/2851	20/787	7/366	6/177	6/97

Figure 3. Association between home blood pressure and stroke risk in the J-HOP study (adapted, with permission, from Hoshide et al.).[50] Abbreviations: CI, confidence interval; HR, hazard ratio; SBP, systolic blood pressure.

in the current setting of increased climate change, and have the potential to change the epidemiology of hypertension.[66]

Variability in home BP has been shown to be predictive of both stroke and CV events,[67,68] and is a key component of the systemic hemodynamic atherothrombotic syndrome.[69] Even variability across just a few home BP measurements is able to predict the occurrence of total and nonfatal CV events as well as total mortality.[68] Day-to-day variability in home BP also predicts hypertensive target organ damage.[70–75] Using data from the J-HOP study, several measures of short-term BP variability were found to be significantly associated with CVD risk

independently of home SBP, circulating B-type natriuretic peptide levels and the urinary albumin–creatinine ratio, with risk increasing as variability increased (Figure 6).[76]

MANAGEMENT OF ANTIHYPERTENSIVE THERAPY

HBPM is a practical way to determine and monitor BP during the day-to-day management of hypertension, providing real-time information on antihypertensive treatment-related changes in BP. The ability of HBPM to provide repeated measures under standard conditions at specific times for an extended period of time makes it ideally suited for evaluating the efficacy of pharmacological antihypertensive therapy. Furthermore, using HBPM as part of the routine management of patients with hypertension might optimize reductions in BP, improve BP control, and reduce target organ damage and CVD risk. Another potential benefit of HBPM is that it facilitates education of patients about their disease, and its management and control, thus encouraging patient-centric care.[77]

BP reduction and control

Nocturnal home BP monitoring documented significant reductions in nighttime home SBP during treatment with angiotensin receptor blocker-based antihypertensive therapy in Japanese patients with nocturnal hypertension.[30] HBPM also showed that morning home BP was significantly decreased in hypertensive patients during angiotensin receptor blocker-based therapy.[42,78]
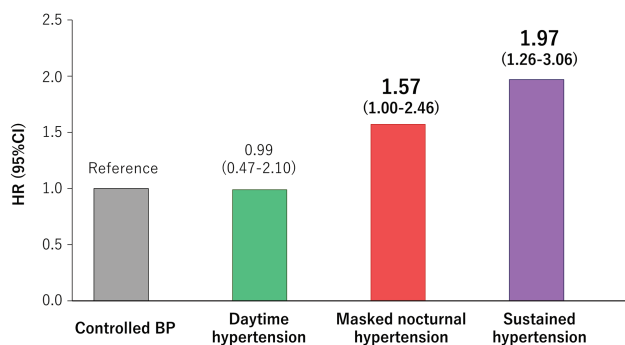
Figure 4. Risk of cardiovascular events based on type of hypertension (adapted, with permission, from Fujiwara *et al.*).[52] Abbreviations: BP, blood pressure; CI, confidence interval; HR, hazard ratio.

Data from several meta-analyses show that use of HBPM during antihypertensive therapy is associated with significant decreases in SBP and DBP compared with usual care,[79–82] and with reductions in antihypertensive medication use and therapeutic inertia, defined as unchanged medication despite elevated BP.[82] Thus, HBPM plays a central role in a stepwise, personalized, optimal 24-hour BP control approach to the management of hypertension (Figure 7).[32]

CV event risk

The association between HBPM parameters and risk of CVD events and mortality supports the use of this approach to monitoring BP and antihypertensive therapy in clinical practice.[77] The Hypertension Objective Treatment Based on Measurement by Electrical Devices of Blood Pressure (HOMED-BP) trial was the first study to evaluate outcomes in patients with hypertension whose antihypertensive therapy was guided by self-measured home BP.[48] The risk of CV death plus stroke and myocardial infarction (the primary endpoint) independently increased by 41% and 47% for each 1 SD increase in baseline and follow-up home SBP, respectively, irrespective of the antihypertensive used.[48] This suggests that reducing home BP is an important goal in patients with hypertension. In the HOMED-BP study, the 5-year risk of primary endpoint events was ≤1% if the home SBP during treatment was ≤131.6 mm Hg,[48] which indicates that the guideline targets for home BP should be sufficient to reduce CVD risk.

DIGITAL MANAGEMENT OF HYPERTENSION AND NEW DEVELOPMENTS

The usefulness of HBPM can be enhanced by the addition of telemonitoring, whereby patients receive feedback from healthcare professionals based on BP readings sent electronically.[83] Incorporation of telemedicine approaches has been shown to significantly reduce both SBP and diastolic BP, and improve BP control, compared with usual care.[84–87] In addition, telemedicine allows provision of effective healthcare services without close interaction, making it ideally suited to maintain effective disease management under pandemic or natural disaster conditions.[83] A telemedicine-based strategy was successfully used to facilitate digital management of hypertension based on individual big data in the aftermath of the Great East Japan Earthquake in March 2011.[88] A web-based HBPM system enabled effective monitoring and strict control of home BP and minimized seasonal variations in BP over the months and years after the earthquake.[88] A comprehensive digital approach to the management of hypertension (the HERB system) is currently under evaluation in a randomized clinical study (the HERB-DH1 trial).[89] Adults with essential hypertension are being managed using the HERB system and standard lifestyle interventions or lifestyle interventions alone. The HERB system app includes an algorithm designed to promote lifestyle modifications in conjunction with medically validated nonpharmacological interventions. The primary endpoint is the change in 24-hour SBP from baseline to 12 weeks and the results are expected in early 2021.[89]

Another promising strategy for HBPM is the use of wearable devices that allow cuff-less, noninvasive, beat-by-beat monitoring of BP. A number of these devices are currently in development by companies with a proven track record in the hypertension field. The development and use of wearable BP monitoring devices were recently reviewed in detail.[90] Several wearable devices have been validated using currently accepted clinical standards[91,92] and one has also shown good agreement with ABPM.[93] These devices could also provide data on environmental conditions, and may also be useful for detecting arrhythmias, such as atrial fibrillation.[94] Further research and developments in this area could improve the accessibility and acceptability of HBPM.

The data provided by HBPM and other wearable hypertension monitoring devices could help inform artificial intelligence strategies to improve the diagnosis and treatment of hypertension. Several studies have investigated these approaches. One machine learning model based on data from 18,258 individuals was able to predict the development of hypertension in a general population.[95] Another artificial intelligence-based prediction model based on time-series BP data and related contextual information used multi-input multi-output deep neural networks to predict both mean BP and BP variability.[96] These approaches could identify patients at risk of developing hypertension, and then help predict BP values and variability to allow the most appropriate therapeutic strategy for each patient.

PERSPECTIVES

HBPM is an important and practical tool for the out-of-office measurement of BP. When performed according to current guidelines and using a validated device, it provides similar data to ABPM but is more widely available and convenient for patients. The introduction of wearable HBPM devices into clinical practice would be expected to make HBPM accessible to a larger number of patients, with the potential to replace ABPM as the out-of-office BP monitoring tool of choice. In addition, devices and systems with additional features such as nocturnal home BP monitoring, and monitoring of temperature and environmental factors alongside home BP, will facilitate a more comprehensive approach to the diagnosis
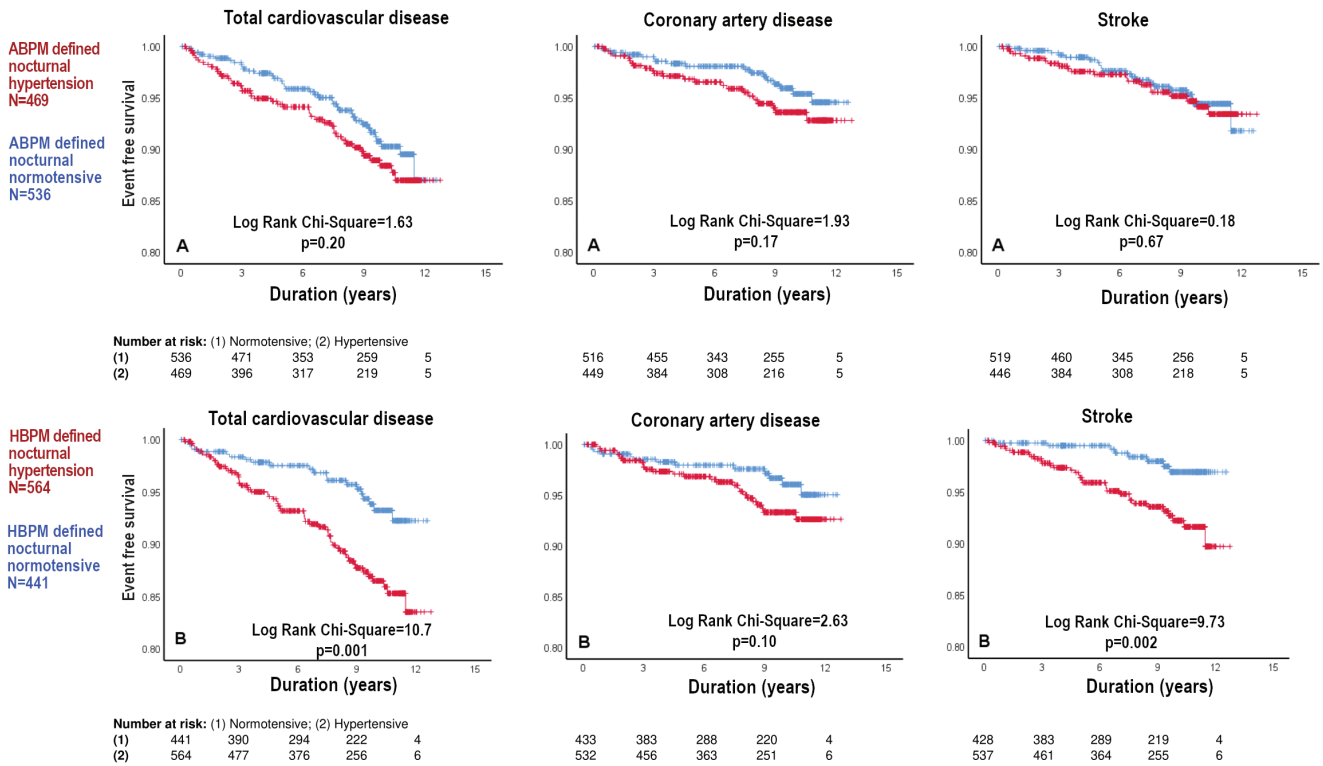
Figure 5. Association between nocturnal hypertension defined using ambulatory (**a**) vs. home (**b**) blood pressure and cardiovascular event risk in the J-HOP study (reproduced, with permission, from Mokwatsi *et al.*).[53]
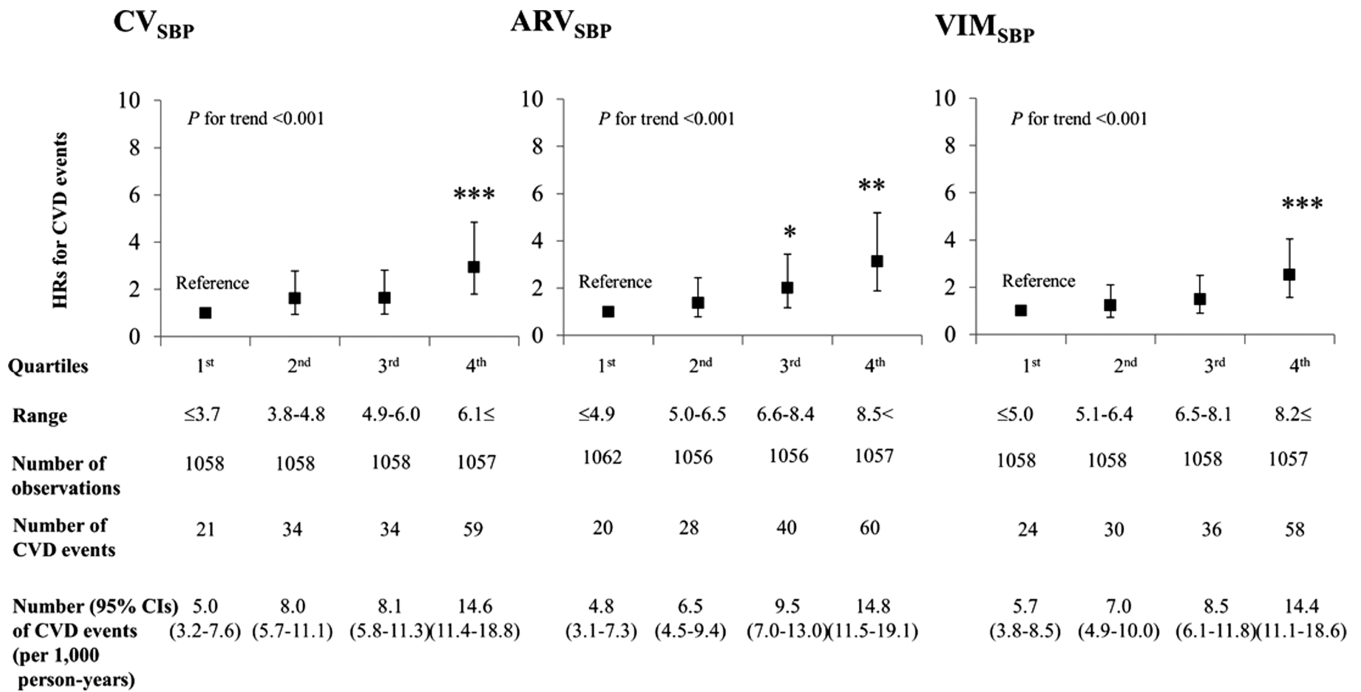
Figure 6. Cardiovascular disease risk by quartiles of home blood pressure variability (reproduced, with permission, from Hoshide *et al.*).[76] Abbreviations: ARV, average real variability; CI, confidence interval; CV, coefficient of variation; CVD, cardiovascular disease; SBP, systolic blood pressure; VIM, variability independent of the mean. *P < 0.05 vs. reference group; **P < 0.01 vs. reference group; ***P < 0.001 vs. reference group.
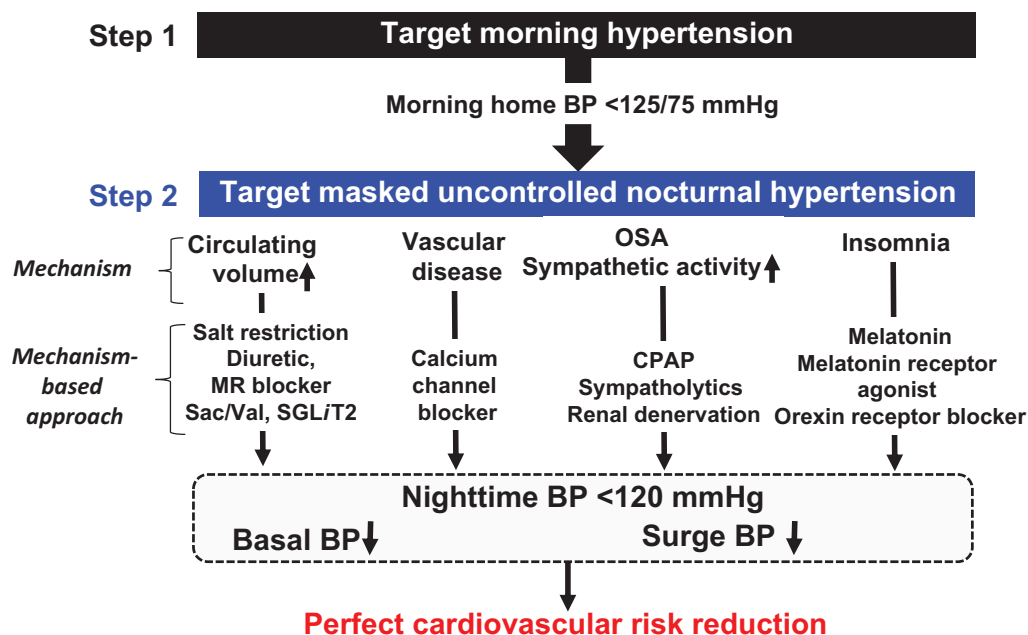
Figure 7. Mechanism-based STEpwise-personalized 24-hour blood pressure control approach (STEP24) (adapted, with permission, from Kario).[32] Abbreviations: BP, blood pressure; CPAP, continuous positive airway pressure; MR, mineralocorticoid receptor; OSA, obstructive sleep apnea; Sac/Val, sacubitril/valsartan; SGLT2i, sodium glucose cotransporter 2 inhibitor.

and treatment of hypertension, and evaluation of CV risk. However, it is also important to note that current use and awareness of HBPM varies between regions and countries, and between specialists and general practitioners.[97] There are also a number of challenges that need to be overcome to facilitate the widespread implementation of an HBPM-based approach to hypertension management. These include a lack of awareness about the clinical value of HBPM, insufficient knowledge about HBPM best practices, and a lack of resources (both time and equipment).[97] Nevertheless, a substantial body of evidence for the prognostic value of home BP measurements highlight the importance of this approach to the management of CV risk factors in patients with hypertension. HBPM can play a key role in anticipation medicine strategies designed to identify increasing risk and predict the onset of CV events based on a series of data collected over time, allowing proactive interventions to reduce risk and eliminate events. Current developments and future advances in HBPM technologies, along with targeted training and education to support their use, will see HBPM continue to feature as an essential component of the continuum of care for hypertension, including diagnosis and both short- and long-term monitoring of the response to antihypertensive therapy.

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