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Circadian hemodynamics in men and women with high blood pressure: dipper vs. nondipper and racial differences

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Abstract

Objective—The ‘nondipping’ pattern of circadian blood pressure (BP) variation is an established independent predictor of adverse cardiovascular outcomes. Although this phenomenon has been widely studied, its underlying circadian hemodynamics of cardiac output and systemic vascular resistance (SVR) have not been well characterized. We evaluated the hypothesis that BP nondipping would be associated with a blunted night-time reduction in SVR in a biracial sample of 140 (63 African-American and 77 white) men and women with elevated clinic BP (130–159/85–99 mmHg).

Methods and results—Twenty-four-hour ambulatory hemodynamics were assessed using standard ambulatory BP monitoring coupled with synchronized ambulatory impedance cardiography. Using the criterion of less than 10% dip in SBP, there were 51 nondippers (SBP dip = $7.3 \pm 2.6\%$) and 89 dippers (SBP dip = $15.5 \pm 3.4\%$). There was minimal change in cardiac output from daytime to night-time in both dippers and nondippers. However, SVR decreased from daytime to night-time, but nondippers compared with dippers exhibited a significantly attenuated decrease in SVR from daytime to night-time (7.8 vs. 16.1%, $P < 0.001$). Relative to their white counterparts, African-Americans also exhibited blunted SBP dipping (10.9 vs. 14.6%, $P < 0.001$) as well as an attenuated decrease in SVR (10.8 vs. 15.6%, $P < 0.001$).

Conclusion—Overall, these findings indicate that blunted night-time BP dipping is associated with impairment of the systemic vasodilation that is characteristic of the night-time sleep period and is especially prominent among African-Americans. In the context of high BP, these findings suggest that nondipping may be a manifestation, or marker, of more advanced vascular disease.

Keywords

blood pressure dipping; cardiac output; hemodynamics; race; systemic vascular resistance

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Conflicts of interest

There are no conflicts of interest.

INTRODUCTION

Ambulatory blood pressure (BP) monitoring (ABPM) studies have established that BP typically exhibits a circadian rhythm characterized by a fall in pressure during the night-time sleep period. However, the magnitude of this fall, or 'dip', in BP shows marked variation between individuals. Most often, BP dips by 10% or more when comparing average night-time sleep BP to the average BP during the daytime awake period. A nondipping circadian BP profile, typically defined as less than 10% fall in average BP from daytime to night-time, is associated with target organ damage [1,2] and is a strong prognostic indicator of cardiovascular morbidity and mortality for both hypertensive and nonhypertensive individuals [1,3–6]. Blunted night-time BP dipping is related to target organ damage in patients with hypertension and is a predictor of cardiovascular morbidity and mortality.

The physiological mechanisms accounting for blunted night-time BP dipping are not well understood [7]. An attenuated fall in sympathetic nervous system (SNS) arousal from daytime waking activities to night-time sleep has been shown to accompany blunted BP dipping [8–10]. Relative body weight also may be an important consideration, with blunted BP dipping more common in obese individuals [11], possibly in association with heightened SNS activity [12,13]. Heightened night-time SNS activity would favor peripheral vascular constriction, resulting in abnormally elevated systemic vascular resistance (SVR) during the sleep period [14]. The contribution of vascular disease to a blunted night-time BP dip is supported by observations that a nondipping circadian BP profile is approximately twice as common in patients with coronary heart disease compared with age-matched healthy controls [15–17]. Blunted BP dipping also has been shown to be related to impaired vascular endothelial function in women with untreated hypertension [18].

Race is another characteristic that has a well documented relation to night-time BP dipping, with African-Americans characterized by diminished BP dipping compared with their white American counterparts [19,20]. African-Americans have a disproportionately high risk of adverse cardiovascular events [21], and BP nondipping in African-Americans is considered a factor that contributes to this increased risk. It is also noteworthy that SVR tends to be relatively elevated amongst African-Americans and may lead to end-organ damage [22]. Numerous studies also have documented that African-Americans exhibit a propensity to greater vascular reactivity during psychosocial stress and other stimuli that trigger SNS arousal [23]. A small pilot study of ambulatory hemodynamics showed that SVR may play a more prominent role for African-Americans compared with whites in the regulation of BP during routine daily activities [24]. The presence of more advanced vascular disease may be one mechanism contributing to these racial differences in circadian hemodynamics [25,26].

The aim of the current study was to examine the hemodynamic determinants of individual differences in circadian BP regulation by combining ABPM with ambulatory impedance cardiography to assess cardiac output (CO) and SVR as well as BP over a 24-h period in a biracial sample of men and women with untreated high BP. Our focus was on understanding the hemodynamics associated with nighttime BP dippers vs. nondippers, and on comparing the hemodynamics of BP dipping in African-Americans compared with whites. Based upon the evidence described above, we hypothesized that a nondipping BP profile would be

characterized by a lesser reduction in SVR from the daytime awake period to night-time sleep. Furthermore, we hypothesized that blunted BP dipping in African-Americans would be accompanied by a more blunted night-time fall in SVR compared with whites. As a secondary aim, we assessed pulse wave velocity (PWV) and carotid artery intima-media thickness (IMT) as an approach to assessing the potential contribution of vascular disease to blunted dipping hemodynamics.

METHODS

Participants

Participants were 140 men ($N=89$) and women ($N=51$) between the ages of 40 and 60 years, including 63 African-Americans and 77 white Americans. BP inclusion criteria were clinic SBP 130–159 mmHg and/or DBP 85–99 mmHg (which includes the JNC VII criteria [27] for Stage 1 hypertension and the upper half of the range defined for prehypertension). Exclusion criteria were BMI more than 35 kg/ m²; age less than 40 years or more than 60 years; current use of BP or cardiovascular medications; diabetes mellitus; previously diagnosed obstructive sleep apnea; pacemaker; atrial fibrillation; myocardial infarction, percutaneous coronary intervention or coronary artery bypass graft surgery within 6 months of enrollment; heart failure; severe uncorrected primary valvular disease; uncorrected thyroid heart disease; oral contraceptive use; pregnancy; HRT; alcohol or drug abuse within 12 months; renal or hepatic dysfunction; dementia; inability to comply with the assessment procedures; and inability to provide informed consent. Participants were recruited by advertisements in the Piedmont region of North Carolina. The study protocol was approved by the Institutional Review Board at Duke University Medical Center. All eligible individuals provided written informed consent prior to participation in the study.

Clinic blood pressure screening

Clinic BP was determined on three separate visits, each approximately 1-week apart. After 5-min seated in a quiet, temperature-controlled room, four seated BP readings, each 2-min apart, were taken using a mercury sphygmomanometer and stethoscope. SBP and DBP for each visit were calculated as the means of the last three readings, and clinic BP eligibility was based upon whether the average of the three mean office BP readings met the study's inclusion criteria.

Ambulatory blood pressure monitoring

Twenty four-hour ambulatory BP (ABP) was assessed on three separate occasions during normal weekdays (Monday–Friday), with an interval of 1 week between monitoring sessions. Ambulatory BP was measured with the Oscar 2 monitor (Suntech Medical Inc., Raleigh, North Carolina, USA), which has been validated by previous investigators [28,29]. The monitor was programmed to take BP measurements every 20 min throughout the waking hours and every 30 min during the night-time sleep period. The night-time sleep period was determined as the period between participants' self-report of when they turned out the lights to go to sleep at night and got out of bed the following morning. The sleep period was further confirmed objectively by 24-h actigraphy monitoring (Mini-Mitter Actiwatch wrist-watch style actigraph; Mini-Mitter Co., Inc., Sunriver, Oregon, USA).

Ambulatory impedance monitor

Impedance cardiography is a noninvasive methodology that measures cardiac function, including the estimation of CO [30]. Although there is no gold standard for measuring CO, impedance cardiography has been validated favorably against most other methods of estimating CO, under resting conditions as well as during challenges such as exercise and changes in posture [31,32]. The ambulatory impedance monitor (AIM; BioImpedance Technology, Inc., Chapel Hill, North Carolina, USA) used in the current study has been validated against traditional laboratory/clinic-based impedance cardiography devices under resting conditions and in response to postural challenge [33,34]. The AIM is a microcomputer-based, wearable bioelectric impedance monitor and signal processing system, utilizing 80 kHz, 2 mA constant sine wave alternating current (AC) was designed for 24-h measurement of CO. The AIM computer section ensemble averages, analyzes and stores the ECG, dZ/dt , and Z_0 waveforms, as well as the computed cardiac function indices during each measurement sequence. A tetrapolar combination of spot and band electrodes was used, as described and validated previously [35]. The AIM was worn on a belt around the waist, with CO measurements activated via a cuff-pressure sensor triggered by the initiation of each ABP measurement; a 20-s ensemble averaged AIM data sample was acquired concurrent with every ABP measurement. The basal thoracic impedance (Z_0), the first derivative of the pulsatile impedance (dZ/dt), and the ECG waveforms from the AIM impedance cardiograph were acquired (each at a 500-Hz sample rate), downloaded to a personal computer, and processed using COP_WIN software (BioImpedance Technology) [36]. In accordance with recommended standards, left ventricular (LV) ejection time was computed as the time interval (ms) between the dZ/dt B-point and X-point, and stroke volume was derived using the Kubicek equation. Heart rate (HR) was derived from the ECG R-R interval. The SVR was derived from the each of the simultaneously recorded ABP and CO values [$SVR \text{ (dyn s cm}^{-5}\text{)} = (\text{mean arterial pressure (MAP)/CO}) \times 80$; where $MAP = (SBP - DBP)/3 + DBP$] [30].

Arterial stiffness

PWV, measured using the Complior (Artech Medical, Pantin, France), was used to assess central artery stiffness [37,38]. With participants supine and resting, pulse pressure waveforms were recorded from the right carotid and right femoral arteries, and PWV (m/s) was calculated from measurements of pulse transit time (s) and the distance (m) travelled by the pulse between the two recording sites. Triplicate measurements were obtained and the average value used to represent PWV.

Carotid artery intima-media thickness

Carotid artery IMT was measured using a high-resolution B-mode ultrasound vascular imaging system (Acuson Aspen, Mountain View, California, USA) with a 10-Mhz linear array transducer. Ultrasound examinations of the far wall of the left and right common carotid arteries (CCAs) were used to acquire longitudinal images spanning 2 cm proximal to the carotid bulb. IMT of the far wall of the left and right CCAs was measured over a 1-cm segment using edge detection software (Carotid Analyzer 5.0.5; Medical Imaging

Applications LLC, Iowa City, Iowa, USA). Far wall measurements only were used as near wall measurements have been shown to have limited reliability [39].

Demographic and psychosocial assessments

Data were collected on age, sex, height, weight, waist and hip circumference, cigarette smoking, alcohol consumption and shift work. BMI was calculated as weight (kg)/height squared (m^2). Waist-to-hip ratio was calculated as waist circumference (cm)/hip circumference (cm).

Statistical analysis

Waking and night-time sleep periods, based on participant self-report and confirmed by wrist actigraphy, were used to calculate mean waking and mean night-time sleep values for ABP, HR, CO and SVR for each participant's three ABPM sessions. Values for the three sessions were averaged to derive a robust measure of waking and night-time ABP and hemodynamics for each participant. Dipping was assessed by subtracting the mean night-time sleep value from the mean waking value for each parameter. Percentage dip for all parameters was assessed by dividing the mean dipping value by the mean wake value and multiplying by 100. BP dipper status was defined as a dip in mean SBP greater or equal to 10% (dipper), or less than 10% (nondipper). Values for CO and SVR were indexed by BSA [$BSA = \text{height (in)} \times \text{weight (lb)} / 3131$] to account for sex differences in body size.

Means ($\pm$ SD) and percentages were calculated for continuous and categorical participant characteristics respectively. One-way analysis of variance tests were used to assess differences in demographic characteristics, BPs, PWV, IMT and hemodynamics as a function of BP dipper status and race. Repeated measures analyses of covariance (ANCOVAs) were used to evaluate group (i.e. dipper status or race) differences in awake vs. sleep BP and hemodynamics. Group (i.e. dipper status or race) differences in the magnitude of BP and hemodynamic dip (i.e. awake minus sleep) were evaluated by ANCOVA tests, controlling for age, sex, BMI and the corresponding awake value for each hemodynamic parameter. PWV and IMT were included as additional covariates in further analyses to evaluate their potential contribution. All statistical analyses were conducted using the SAS system (SAS 9.2, SAS Institute, Cary, North Carolina, USA) with significance set at $P = 0.05$.

RESULTS

Demographic characteristics

Demographic and anthropometric characteristics of the study cohort are shown in Table 1. The 140 participants included 34 African-American women, 29 African-American men, 17 white women and 60 white men, with a mean age of 45.5 ± 8.5 years and a screening BP of 140/90 mmHg. Thirty-four percent of the samples ($n=51$) were classified as nondippers with an average SBP dip of $7.3 \pm 2.6\%$. Women composed 40% of the dipper subsample and 35% of the nondipper subsample. Nondippers exhibited significantly higher BMI and clinic DBP (P s < 0.05) compared with dippers (Table 1). Whereas white participants were older, African-Americans exhibited higher clinic DBP (P s < 0.05). Women also composed a

greater proportion of the African-American study sample (54%) compared with the white study sample (22%).

Dipper status and race differences in arterial disease

Table 1 also summarizes PWV and IMT for the study sample. Because of the sex and BMI imbalances by group, we further evaluated possible differences in PWV and IMT by dipper status and race using ANCOVAs that included age, sex and BMI as covariates. No differences were noted between nondippers and dippers in PWV (adjusted means 7.26 ± 1.09 vs. 7.00 ± 1.23 , $P=0.198$) and IMT (adjusted means 0.66 ± 0.13 vs. 0.65 ± 0.1 , $P=0.503$). BMI was associated with increased PWV ($P=0.038$), as was advancing age ($P<0.001$), but not sex ($P=0.689$). IMT was lower in women than men (0.62 ± 0.09 vs. 0.67 ± 0.12 , $P=0.019$), and also increased with advancing age ($P<0.001$), but was unrelated to BMI ($P=0.877$). African-Americans compared with whites evidenced both greater PWV (7.33 ± 1.17 vs. 6.88 ± 1.19 , $P=0.025$) and increased IMT (0.67 ± 0.09 vs. 0.64 ± 0.12 , $P=0.02$).

Hemodynamics of night-time blood pressure dipping

As shown in Table 2, nondippers exhibited significantly higher sleep time SBP, DBP and sleep SVR index (SVRI) (all P s ≤ 0.05) compared with dippers (Table 1). Regarding race, white participants had greater awake and sleep cardiac index (CI), whereas African-Americans exhibited higher awake DBP, night-time sleep SBP and DBP, as well as higher awake and sleep SVRI (all P s ≤ 0.05). For the study sample as a whole, night-time dipping was associated with an average fall in SBP of 17.7 ± 6.8 mmHg and an average fall in DBP of 15.1 ± 5.1 mmHg. Hemodynamically the night-time BP dip was accompanied by an average fall in HR of 12 ± 5 bpm, a very slight increase in CI of 0.11 ± 0.44 l/min/m² and a decrease in SVRI of 442 ± 516 dyn-s-cm⁻⁵ · m². Intercorrelations between the hemodynamic dipping variables are shown in Table 3.

Day–night hemodynamics by dipper status

Differences in mean awake and night-time sleep BP were examined with a 2 (i.e. time, awake vs. sleep) $\times$ 2 (i.e. group, dipper vs. nondipper) repeated measures ANCOVA controlling for age, sex and BMI. There were no significant main effects for age, sex or BMI across awake and nighttime sleep BP. There were significant main effects of time (awake vs. sleep, $P<0.001$), and dipper status ($P<0.001$), and importantly, a significant time $\times$ dipper status interaction ($P<0.001$), for ambulatory SBP. As depicted in Fig. 1, SBP decreased significantly from the awake to sleep period in both dippers and nondippers; however, nondippers exhibited a smaller decline in SBP compared with dippers ($P<0.001$). A similar pattern was observed for DBP, with Time ($P<0.001$), dipper status ($P<0.001$) and a time $\times$ dipper status interaction ($P<0.001$). Again, nondippers exhibited a smaller day–night decline in DBP compared with dippers ($P<0.001$).

For HR, there was a significant effect for time (awake vs. sleep, $P=0.017$), due to HR decreasing from daytime to night-time, and a time $\times$ dipper status interaction ($P=0.01$) reflecting a lesser day–night decrease in HR in nondippers. There also was a significant sex effect ($P<0.001$) associated with generally higher HR in women than men. For CI, there was

no significant main effect of time ($P=0.395$), or dipper status ($P=0.977$), nor was the time $\times$ dipper status interaction significant ($P=0.645$). There was a significant main effect for BMI ($P<0.001$), due to an inverse association between BMI and CI, and for age ($P<0.001$), reflecting lower CI in older participants. As shown in Table 2, CI changed minimally from awake to sleep and dippers and nondipper did not differ in this respect ($P=0.618$). For SVRI, there was a significant main effect for age ($P=0.003$), with SVRI increasing with advancing age. There was also a main effect for BMI ($P<0.001$), with greater relative weight associated with higher SVRI. Neither the main effect of Time ($P=0.430$), nor the effect for dipper status ($P=0.104$) were significant for SVRI. However, there was a significant time $\times$ dipper status interaction ($P<0.001$). As depicted in Fig. 2, the awake to sleep period decline in SVRI was reduced among nondippers compared with dippers ($P<0.001$). Adding PWV and IMT as covariates in the latter model altered minimally the dipper vs. nondipper differences in SVRI dipping ($P=0.001$).

Day–night hemodynamics by race

Analyses were repeated to examine differences in mean awake and night-time sleep BP as a function of race. Significant main effects for time ($P<0.001$), race ($P=0.001$) and the time $\times$ race interaction ($P<0.001$) were observed for ambulatory SBP. As depicted in Fig. 3, African-Americans exhibited less of a dip in SBP from the awake to sleep period compared with whites ($P<0.001$). Effects for DBP, time ($P<0.001$), race ($P<0.001$) and the time $\times$ race interaction ($P=0.001$) were consistent with this pattern and confirmed by a race difference in DBP dipping ($P=0.011$). There were no significant main effects for age, sex or BMI across awake and night-time sleep BP.

HR was generally higher in African-Americans than whites ($P=0.03$), but there was no time $\times$ race interaction ($P=0.785$), or race difference in the magnitude of HR dip ($P=0.365$). For CI, there was no significant main effect of time ($P=0.436$), or the time $\times$ race interaction ($P=0.241$). There was a significant main effect of race ($P=0.025$), indicating that whites exhibited higher mean CI compared with African-Americans, across both the awake and nighttime sleep periods, with a marginally greater CI dip in African-Americans ($P=0.074$). For SVRI, there was a main effect for race ($P<0.001$) and a time $\times$ race interaction ($P=0.005$). As shown in Table 1 and Fig. 4, SVRI was elevated amongst African-Americans compared with whites, both during daytime waking hours and during night-time sleep. Furthermore, there was a substantial racial difference in SVRI dipping from the average daytime awake period to night-time sleep period, with African-Americans exhibiting significantly less night-time decrease in SVRI compared with whites ($P<0.001$). After adding PWV and IMT as covariates in the latter model, race differences in SVRI dipping remained statistically significant ($P=0.022$). Finally, an exploratory analysis limited to only those participants classified as nondippers showed that night-time SVRI amongst African-American nondippers also was more elevated compared with their white nondipper counterparts ($P=0.021$).

DISCUSSION

In this biracial sample of men and women with untreated high BP, over one-third exhibited a 'nondipper' pattern of circadian BP variation. As hypothesized, the nondipping BP pattern was accompanied by a blunted fall in night-time SVR compared with dippers. Consistent with prior studies [10,19,20], African-Americans also exhibited blunted nighttime BP dipping compared with whites. Again, this blunted BP dipping pattern was accompanied by an attenuated night-time fall in SVR amongst African-Americans compared with whites. To our knowledge, this is the first study to show that the circadian variation in BP is driven by a parallel circadian variation in hemodynamics that is characterized by a night-time lowering of BP due to a reduction in SVR. This finding is in direct contrast to the prevailing view of circadian hemodynamics, apparently based on the observations of Veerman *et al.* [40] that the circadian BP profile is associated with an *increase* in SVR during nighttime sleep. However, their study was based upon a sample of only eight young healthy men with normal BP, and SVR was estimated from the pulse contour method derived from the arterial BP pulsatile waveform.

Several lines of evidence indicate that SVR is more likely to decrease than to increase during the night-time sleep period. It is well established from-tilt table studies that the stabilized response of shifting from a supine to upright or standing posture is a 15–30% increase in HR, and a 30–40% increase in SVR [41]; in other words, relative to standing, SVR is reduced by 30–40% when supine. Casiglia *et al.* [42] observed that forearm vascular resistance (FVR), assessed using strain-gauge plethysmography, decreased with the fall in BP during night-time sleep in patients confined to bed. This fall in FVR was evident in normotensive and most of the hypertensive patients evaluated and was considered to be a phenomenon that was largely independent of physical activity.

There are likely multiple mechanisms accounting for a diurnal variation in SVR. The SNS appears to play a pivotal role, with SNS activity decreasing from the daytime active period to the night-time sleep period, and the magnitude of this variation directly related to the degree of night-time BP dipping [9]. The aforementioned study also noted an association between heightened vascular alpha-1-adrenergic receptor sensitivity and blunted night-time BP dipping, reflecting a propensity to vasoconstrictor activity even when SNS arousal declines. Evidence that alpha-1-adrenergic receptor sensitivity may be upregulated, whereas beta-adrenergic receptors are down-regulated in African-Americans is also consistent with our current observations for overall elevated SVR and blunted SVR dipping in African-Americans compared with whites [43]. In the current study, we examined central aortic PWV as an index of vascular stiffness, and carotid IMT as a measure of atherosclerosis. Although neither of these measures showed a robust association with night-time BP dipping or with SVR dipping in the sample as a whole, we did observe that both PWV and IMT were greater in African-American participants. However, perhaps because both PWV and IMT are measures of vascular disease in major conduit vessels, rather than resistance vessels, we did not find them to account for differences in SVR dipping. Indeed, mechanisms contributing to a reduction in night-time SVR dipping are more likely to originate in the resistance vessels of the systemic microvascular circulation. Remodeling of the resistance vessels, resulting in vascular hypertrophy, has long been accepted as a micro-vascular adaptation that contributes

to increased SVR in hypertension [44]. This structural modification causes a thickening of the resistance vessel walls and a reduction in lumen diameter, limiting vasodilatory capacity. Minimal FVR (MFVR), utilizing strain-gauge plethysmography, provides a noninvasive approach to estimating the presence and degree of vascular hypertrophy. Supporting the role of vascular hypertrophy as a mechanism contributing to blunted night-time BP dipping, studies have shown that MFVR is elevated in nondippers compared with dippers [45,46]. This evidence is consistent with the likelihood that vascular hypertrophy contributes to the nondipping SVR pattern characterizing the BP nondipper in the current study. Recent evidence that MFVR is directly related to SVR amongst African-Americans is consistent with the notion that vascular hypertrophy is also contributing to the increased likelihood of a nondipping circadian BP profile in African-Americans [47]. Vascular endothelial vasodilator function also may be a contributing factor to blunted SVR dipping, with a recent study of postmenopausal women reporting that impaired flow-mediated brachial artery dilation was associated with blunted night-time BP dipping [18]. Overall, the association of nondipping night-time BP with elevated SVR in men and women with high BP is consistent with the interpretation that nondipping is a marker of the presence of microvascular disease.

The clinical significance of a blunted fall in BP during the night-time sleep period is well documented. Nondipping is associated with an increased risk of adverse clinical events, including myocardial infarction and stroke, and is also associated with the development of cardiac LV hypertrophy (LVH), itself an important prognostic marker of heightened risk for adverse cardiovascular events [2]. As noted by Hinderliter *et al.* [22,48], higher resting SVR amongst African-Americans is likely a causal factor in their higher prevalence of LVH [49]. Our current observations that SVR is higher both during the daytime and night-time, and that the night-time fall in SVR is attenuated in African-Americans compared with whites, especially amongst those with a nondipping BP profile, provides support for SVR contributing to racial differences in the prevalence of LVH. African-American nondippers also may be especially vulnerable in view of our evidence that amongst nondippers, they further evidence more elevated night-time SVR than observed in white nondippers.

Strengths of our study include the derivation of individual differences in the diurnal hemodynamic profile averaged across three 24-h monitoring studies and concurrent assessment of BP, CO and SVR via 24-h ambulatory monitoring. Limitations of our study include the use of impedance cardiography to estimate the absolute values of CO. However, the emphasis of our observations is on within-individual changes in hemodynamics over the course of 24-h ambulatory monitoring, and impedance cardiography is considered to be especially robust at tracking changes over time within individuals [30,32]. Our inclusion of PWV and IMT as indices of vascular disease is a study limitation in that they focus on large conduit arteries, whereas it is the microvasculature that is likely involved in the regulation of SVR. A further study limitation is that whereas sleep apnea was an exclusion criterion, the possibility that apnea may have been undiagnosed in some participants cannot be ruled out in the absence of a polysomnographic sleep study.

In summary, our observations indicate that an attenuated night-time fall in SVR characterizes the nondipping BP profile, which is more prominent among African-

Americans, and is a diurnal hemodynamic pattern likely reflecting the presence of vascular disease and promoting the development of LVH.

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Subject Codes: Clinical Studies, Mechanisms.

Abbreviations

ABP	ambulatory blood pressure
ABPM	ambulatory blood pressure monitoring
AIM	ambulatory impedance monitoring
BP	blood pressure
CI	cardiac index
CO	cardiac output
FVR	forearm vascular resistance
HR	heart rate
IMT	intima–media thickness
LVH	left ventricular hypertrophy
MAP	mean arterial pressure
MFVR	minimum forearm vascular resistance
PWV	pulse wave velocity
SNS	sympathetic nervous system
SVR	systemic vascular resistance
SVRI	systemic vascular resistance index

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FIGURE 1.

Daytime awake and night-time sleep period mean ($\pm$ standard error) SBP by dipper status. *P* values shown within the figure indicate the results of a 2 (i.e. time, awake vs. sleep) $\times$ 2 (i.e. group, dipper vs. nondipper) repeated measures analyses of covariance controlling for age, sex and BMI. An analyses of covariance test of the SBP dip, controlling for age, sex, BMI and awake SBP confirmed that nondippers exhibited a smaller decline in SBP compared with dippers ($P < 0.001$).

FIGURE 2.

Daytime awake and night-time sleep period ($\pm$ standard error) systemic vascular resistance index by dipper status. *P* values shown within the figure indicate the results of a 2 (i.e. time, awake vs. sleep) $\times$ 2 (i.e. group, dipper vs. non-dipper) repeated measures analyses of covariance controlling for age, sex and BMI. An analyses of covariance test of the systemic vascular resistance index dip, controlling for age, sex, BMI and awake systemic vascular resistance index confirmed that nondippers exhibited a smaller decline in systemic vascular resistance index compared with dippers ($P < 0.001$).

FIGURE 3.

Daytime awake and night-time sleep period ($\pm$ standard error) SBP by race. *P* values shown within the figure indicate the results of a 2 (i.e. time, awake vs. sleep) $\times$ 2 (i.e. group, African-American vs. white) repeated measures analyses of covariance controlling for age, sex and BMI. An analyses of covariance test of the SBP dip, controlling for age, sex, BMI and awake SBP confirmed that African-Americans exhibited a smaller decline in SBP compared with whites ($P < 0.001$).

FIGURE 4.

Daytime awake and night-time sleep period ($\pm$ standard error) systemic vascular resistance index by race. *P* values shown within the figure indicate the results of a 2 (i.e. time, awake vs. sleep) $\times$ 2 (i.e. group, African-American vs. white) repeated measures analyses of covariance controlling for age, sex and BMI. An analyses of covariance test of the systemic vascular resistance index dip, controlling for age, sex, BMI and awake systemic vascular resistance index confirmed that African-Americans exhibited a smaller decline in systemic vascular resistance index compared with whites ($P < 0.001$).

TABLE 1

Demographic, anthropometric and clinical characteristics of the study sample by blood pressure dipper status and race

	Dipper, <i>n</i> =89	Nondipper, <i>n</i> =51	White, <i>n</i> =77	African-American, <i>n</i> =63	All, <i>n</i> =140
Age (year)	45.8 ± 8.4	44.9 ± 8.9	47.1 ± 9.1	43.6 ± 7.4	45.5 ± 8.5
Sex (<i>n</i> , %female)	36 (40)	18 (35)	23 (30)	31 (49)	54 (39)
BSA (m ²)	1.98 ± 0.2	2.04 ± 0.2	2.02 ± 0.2	1.99 ± 0.2	2.01 ± 0.2
BMI (kg/m ²)	27.9 ± 4	29.3 ± 3.5	27.9 ± 3.8	29.1 ± 3.8	28.4 ± 3.8
WHR	0.89 ± 0.1	0.88 ± 0.1	0.89 ± 0.1	0.88 ± 0.1	0.89 ± 0.1
Clinic SBP (mmHg)	139.7 ± 7.1	140.7 ± 8.1	139.2 ± 7.1	141.1 ± 7.8	140.05 ± 7.5
Clinic DBP (mmHg)	88.8 ± 5.2	91.6 ± 4.9	88.5 ± 5.2	91.5 ± 4.8	89.8 ± 5.2
Arterial stiffness PWV (m/s)	7.00 ± 1.21	7.21 ± 1.10	6.98 ± 1.17	7.19 ± 1.17	7.08 ± 1.17
Carotid artery IMT (mm)	0.64 ± 0.01	0.66 ± 0.13	0.64 ± 0.01	0.66 ± 0.01	0.65 ± 0.11

Note: Bolded indicates significant between group differences. *P* value less than 0.05. IMT, intima-media thickness, PWV, pulse wave velocity, WHR, waist-to-hip ratio.

Hemodynamic awake, sleep and dipping characteristics of the study sample by blood pressure dipper status and race

TABLE 2

	Dipper, n=89	Nondipper, n=51	White, n=77	African-American, n=63	All, n=140
Awake SBP (mmHg)	136.4 ± 10.7	138.9 ± 11.7	136.1 ± 12	138.8 ± 9.6	137.3 ± 11
Awake DBP (mmHg)	83.6 ± 8.3	85.8 ± 8.2	82.4 ± 8.6	86.7 ± 7.3	84.3 ± 8.3
Awake HR (bpm)	79 ± 9	79 ± 79	77 ± 9	81 ± 9	79 ± 9
Awake CI (l/min per m ²)	2.87 ± 0.70	2.83 ± 0.72	2.95 ± 0.77	2.73 ± 0.63	2.84 ± 0.71
Awake SVRI (dyn-s-cm ⁻⁵ · m ²)	3176 ± 833	3306 ± 886	3055 ± 825	3420 ± 843	3239 ± 880
Sleep SBP (mmHg)	115.1 ± 10.5	128.2 ± 10.7	115.9 ± 12.3	123.8 ± 10.5	119.39 ± 12.2
Sleep DBP (mmHg)	66.1 ± 8.4	75.2 ± 8.8	65.9 ± 9.2	72.9 ± 8.4	69.1 ± 9.5
Sleep HR (bpm)	66 ± 9	68 ± 8	64 ± 9	69 ± 8	67 ± 9
Sleep CI (l/min per m ²)	2.77 ± 0.68	2.71 ± 0.71	2.86 ± 0.69	2.62 ± 0.67	2.75 ± 0.69
Sleep SVRI (dyn-s-cm ⁻⁵ · m ²)	2643 ± 820	3046 ± 828	2547 ± 783	3056 ± 831	2774 ± 841
SBP dip (mmHg)	21.3 ± 4.7	10.2 ± 3.6	19.7 ± 5.9	15.2 ± 7.1	17.7 ± 6.8
SBP dip (%)	15.6 ± 3.4	7.3 ± 2.6	14.6 ± 4.4	10.9 ± 4.9	12.9 ± 5
DBP dip (mmHg)	17.4 ± 4.0	10.4 ± 3.7	16.1 ± 4.8	13.9 ± 5.2	15.1 ± 5.1
DBP dip (%)	20.9 ± 4.8	12.2 ± 4.4	19.76 ± 6.0	15.9 ± 5.9	18.1 ± 6.2
HR dip (bpm)	13 ± 5	11 ± 5	12 ± 5	12 ± 5	12 ± 5
HR dip (%)	17 ± 6	13 ± 6	16 ± 6	15 ± 6	16 ± 6
CI dip (l/min per m ²)	0.09 ± 0.41	0.12 ± 0.49	0.10 ± 0.43	0.11 ± 0.46	0.11 ± 0.44
CI dip (%)	2.5 ± 14.0	2.8 ± 16.0	2.0 ± 14.5	3.33 ± 14.8	2.6 ± 14.6
SVRI dip (dyn-s-cm ⁻⁵ · m ²)	531 ± 474	257 ± 554	502 ± 492	368 ± 539	442 ± 516
SVRI dip (%)	16.1 ± 14.7	7.8 ± 18.6	15.6 ± 15.5	10.8 ± 17.4	12.9 ± 15.7

Note: Bolded means indicates between group differences. P value less than 0.05. CI, cardiac index; HR, heart rate; SVRI, systemic vascular resistance index.

TABLE 3

Intercorrelations (Pearson *R* values) between hemodynamic dipping (awake minus sleep) parameters for the total study sample

<i>N</i> =140	DBP dip	HR dip	CI dip	SVRI dip
SBP dip	0.76	0.22	−0.01	0.26
DBP dip		0.29	−0.16	0.44
HR dip			0.04	0.07
CI dip				−0.83

Note: Bolded correlations significant at *P* value less than 0.05. CI, cardiac index; HR, heart rate; SVRI, systemic vascular resistance index.