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# Comparison of nighttime measurement schedules using a wrist-type nocturnal home blood pressure monitoring device

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## Abstract

We investigated the optimal nighttime home blood pressure (BP) measurement schedule for wrist BP monitoring. Fifty hypertensive patients (mean age 68.9 ± 11.3 years) self-measured their nighttime BP hourly using a wrist-type nocturnal home BP monitoring device at home on two consecutive nights. Using the average 7.2 ± 1.5 measurements per night, we compared the clock-based index (average of three measurements at 2:00, 3:00, and 4:00 a.m.) and the bedtime-based index (average of three measurements at 2, 3, and 4 h after bedtime). The clock-based average was significantly higher than the bedtime-based average for both systolic BP (2.7 ± 8.2 mmHg, $P = .002$) and diastolic BP (1.9 ± 5.1 mmHg, $P < .001$). Compared to the average of all measurements throughout a night (the same definition of ambulatory BP monitoring, ie, from the time point of going to bed to awakening), the clock-based average was comparable (systolic/diastolic BP: −0.5 ± 5.5/−0.2 ± 3.7), whereas the bedtime-based average was significantly lower (−3.3 ± 5.0/−2.1 ± 3.6). Thus, the repeated measurement of wrist-measured nighttime BP at three clock-based time points per night provided reliable values. Further prospective studies of larger populations are required to confirm the optimal nighttime BP measurement schedule for wrist BP monitoring for the prediction of cardiovascular events.

## 1 | INTRODUCTION

Nighttime blood pressure (BP) during sleep obtained by ambulatory BP monitoring (ABPM) has been reported as a strong predictor of cardiovascular events.[1–3] ABPM has been a gold standard to evaluate nighttime blood pressure, but ABPM has usually been performed over only a single 24-h day and may not capture patients' 'real BP' if they moderate their alcohol drinking or eating on the day of the monitoring. Recent advances in the development of a home BP monitoring (HBPM) device equipped with an automated BP measurement function during sleep have enabled users to repeatedly measure their BPs over a long period.[4,5] There is accumulating evidence that nighttime home BP predicts target organ damage[6,7] and future cardiovascular events.[8] However, both ABPM and HBPM may interfere with sleep quality due to device's cuff inflation and measurement noise.

A newly developed wrist-type nocturnal HBPM device (HEM-9601T; Omron Healthcare) reduces the discomfort induced by cuff inflation and measurement noise. The BP values measured by the HEM-9601T were confirmed to be reliable both under laboratory conditions[9] and real-world sleeping conditions at home.[10] Although these reliable nocturnal HBPM devices has been developed and the evidence of nighttime home BP measurements has been accumulating, the optimal nighttime home BP measurement schedule has not been established. Some studies have used a clock-based BP measurement schedule and other studies preset the measurement timing as the elapsed time after the subject has gone to bed.[4] In the present study, we investigated the optimal measurement schedule for wrist BP monitoring during sleep at home.

## 2 | SUBJECTS AND METHODS

### 2.1 | Study design

This was a post-hoc analysis using wrist-measured BP data obtained from our comparison study of nighttime home BP readings measured by the HEM-9601T wrist device (NightView; Omron Healthcare) and an upper-arm device (HEM-9700T; Omron Healthcare).[10] Details of the comparison study design have been published.[10] Briefly, 50 hypertensive patients with antihypertensive treatment (mean age 68.9 ± 11.3 years) were asked to measure their nighttime BP during sleep at home for two consecutive nights. They were instructed to wear both the wrist and upper-arm devices on the same non-dominant arm and to start the nighttime measurement mode just before going to bed each night.

During the nighttime measurement mode, the wrist device was preset to measure BP every hour on the hour, and the upper-arm device was preset to activate 3 min later than the activation of the wrist device. The study protocol was approved by the institutional review board of Jichi Medical University School of Medicine (rin-A19-241). The study protocol was registered on a clinical trials registration site (University Hospital Medical Information Network Clinical Trials Registry, UMIN000041540). All participants provided written informed consent.

### 2.2 | BP measurement devices

The HEM-9601T NightView is an automatic oscillometric device for self-measuring BP at the wrist, equipped with the algorithm for supine position measurements.[9] The HEM-9700T is an automatic upper arm-type device for the self-measurement of BP.[11] Both the wrist device and the upper-arm device can be preset at bedtime to measure the wearer's BP during sleep. For the present study, we used only the wrist BP data measured by the NightView.

### 2.3 | Nighttime BP measurement index

The participants' nighttime BP values were measured every hour on the hour after going to bed during the nighttime measurement mode. Of those values, the average of three readings measured at 2:00, 3:00 and 4:00 a.m. were calculated as a clock-based index, and the average of three readings measured at 2, 3 and 4 h after the participant's bedtime were calculated as a bedtime-based index.

### 2.4 | Statistical analyses

All statistical analyses were performed using the SAS ver. 9.4 software program (SAS Institute). Pairwise differences between the nighttime BP indices were tested using a paired *t*-test. Between-group differences were examined with Welch's *t*-test. Mixed-effects repeated measures models were used to evaluate repeated measurements considering the time points of the measurements. All of the data processing and analyses were independently conducted at the Global Analysis Center of BP (GAP) at the Jichi Medical University COE Cardiovascular Research and Development (JCARD) Center.

## 3 | RESULTS

### 3.1 | Participant characteristics

All 50 participants were hypertensive patients with antihypertensive treatment. The mean age was 68.9 ± 11.3 years, 54% were male, and the average body mass index (BMI) was 25.8 ± 3.4 kg/m$^2$. The prevalence of regular alcohol use was 24%; current smoking, 2%; diabetes mellitus, 22%; hyperlipidemia, 42%; chronic kidney disease, 4%; hyperuricemia, 24%; history of cardiovascular disease, 22%; and history of heart failure, 4%.[10]

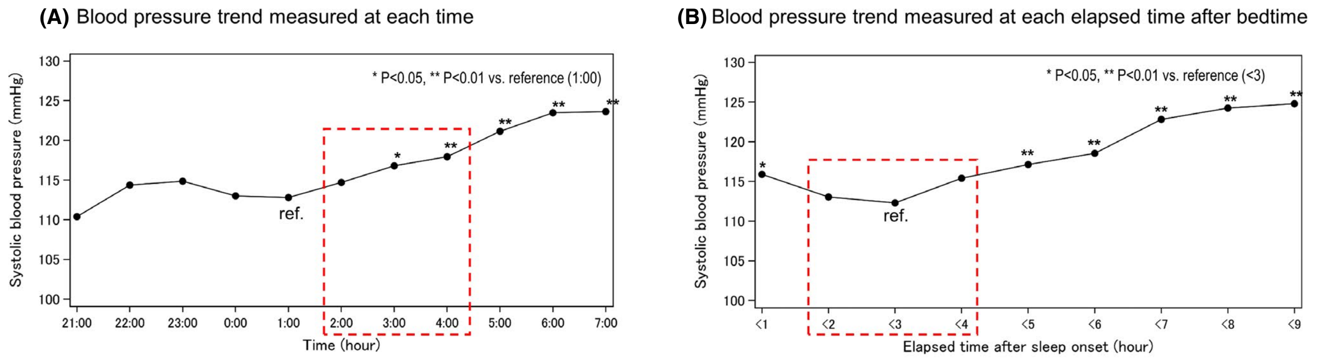
### 3.2 | Wrist BP time trend during sleep

The Figure 1 shows the time trend in systolic BP (SBP) measured by the wrist nocturnal HBPM device during sleep. Using a mixed-effects model, we calculated the least square means by the clock-based time (Figure 1A) and by the elapsed time after the participant went to bed (Figure 1B). Nighttime BP values were measured every hour on the hour after the participant went to bed, and thus the BP values that were in the 'elapsed time after bedtime <1' category are the BP values measured at 0–59 min after the participant went to bed. Measurement time points with <10 measurements (ie, 8:00, 9:00, 10:00 and 11:00 a.m. for the clock-based analysis and <10 h and <11 h for the bedtime-based analysis) were excluded from the mixed-effects model analysis.

In the clock-based time trend analysis, the least square mean at 1:00 a.m. was the lowest, and then the values increased with time. In the bedtime-based time trend analysis, the SBP values measured at <3 h after bedtime were the lowest, and then the values increased with the time that had elapsed. Similar results were observed in the diastolic BP (DBP) time trend (Figure S1).

### 3.3 | Comparison of the nighttime BP indices

The average values of the wrist-measured BP readings per night according to the different nighttime indices are presented in the Table 1. Of the two-night nighttime measurements from 50 patients, the 93




| Time, hr | 21:00 | 22:00 | 23:00 | 0:00 | 1:00 | 2:00 | 3:00 | 4:00 | 5:00 | 6:00 | 7:00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of measurements | 10 | 30 | 60 | 75 | 85 | 89 | 86 | 84 | 82 | 57 | 21 |
| Systolic BP, mmHg | 110.4 | 114.4 | 114.9 | 113.0 | 112.8 | 114.7 | 116.8 | 117.9 | 121.1 | 123.5 | 123.6 |

| Elapsed time after bedtime, hr | <1 | <2 | <3 | <4 | <5 | <6 | <7 | <8 | <9 |
|---|---|---|---|---|---|---|---|---|---|
| Number of measurements | 96 | 95 | 94 | 94 | 93 | 87 | 70 | 43 | 17 |
| Systolic BP, mmHg | 115.9 | 113.0 | 112.3 | 115.4 | 117.1 | 118.5 | 122.8 | 124.2 | 124.8 |

**FIGURE 1** Mixed-effects analysis of the time trend in wrist-measured nighttime systolic blood pressure. Plots represent the estimated systolic BP values at each time point calculated by a mixed-effects model. BP, blood pressure; ref, reference. (A) The blood pressure trend at each time. The total number of measurements for the analysis was 679. Fifteen readings measured after 8:00 (<10 measurements at each time point) were excluded from the mixed-effects model analysis. (B) The blood pressure trend measured at each elapsed time after the participants' bedtimes. The total number of measurements for the analysis was 689. Five readings measured >10 h after the bedtimes (<10 measurements at each time point) were excluded from the mixed-effects model analysis

nights with at least one measurement at 2:00, 3:00, or 4:00 a.m. were used to compare the nighttime BP indices. The average SBP/DBP of all of the interval measurements (mean 7.4 ± 1.3 readings) [all-average index] was 116.4 ± 12.3/67.1 ± 8.0 mmHg. The average of three measurements at 2:00, 3:00, and 4:00 a.m. (mean 2.8 ± 0.5 readings) [clock-based index] was 115.8 ± 13.4/66.8 ± 8.0 mmHg, and the average of the measurements at 2, 3, and 4 h after bedtime [bedtime-based index] was 113.1 ± 14.1/65.0 ± 9.4 mmHg. The difference between the clock-based index and the all-average index was not significant for either SBP (−0.5 ± 5.5 mmHg, $P = .337$) or DBP (−0.2 ± 3.7 mmHg, $P = .530$), whereas the difference between the bedtime-based index and the all-average index was significant for both SBP (−3.3 ± 5.0 mmHg, $P < .001$) and DBP (−2.1 ± 3.6 mmHg, $P < .001$). The clock-based average was significantly higher than the bedtime-based average for both SBP (2.7 ± 8.2 mmHg, $P = .002$) and DBP (1.9 ± 5.1 mmHg, $P < .001$). The average sleep duration (from the first measurement time to the last measurement time during the nighttime measurement mode) was 7.7 ± 1.3 h The difference between the clock-based average and the bedtime-based average was not significantly different when compared by sleep duration and sleep timing (Table S1).

## 4 | DISCUSSION

This is the first study to investigate the optimal schedule for monitoring nighttime BP by a wrist HBPM device at home. The results showed that the clock-based average of wrist BP values measured at 2:00, 3:00, and 4:00 a.m. was significantly higher than the average of the BP values measured at 2, 3, and 4 h after the participants' bedtimes. The clock-based average was comparable to the average of all BP measurements with 60-min intervals throughout a night, while the bedtime-based average was significantly lower than the all-interval average.

### 4.1 | Nighttime BP trend during sleep

In the two-night BP measurements of the 50 hypertensive patients, the BP values were not consistent throughout the night, with the lowest value at 1:00 a.m. or 2–3 h after bedtime. In the J-HOP nocturnal study using an upper arm-type HBPM device equipped with a nighttime BP measurement function, there was no significant difference between the BP levels measured at 2:00 and 3:00 a.m., but that measured at 4:00 a.m. was slightly higher (by 1.5 mm Hg systolic and 1.6 mm Hg diastolic).[12] The nighttime ambulatory BP is generally calculated as the average of the BP values throughout the sleep period, and thus the average of readings including lower and higher values is close to the 'real nighttime BP.'

### 4.2 | Nighttime BP measurement schedule and frequency

In this study, the patients simultaneously wore the wrist 11and upper-arm HBPM devices on the same arm, and the nighttime BP measurements were conducted every hour on the hour during sleep, which is similar to the method that is commonly used for ABPM. Even under these somewhat uncomfortable conditions, not much frequent sleep

**TABLE 1** Comparison of blood pressure indices of nocturnal home blood pressure monitoring (n = 93)

| | All-average | Clock-based | Bedtime-based | Clock vs. All | | Bedtime vs. All | | Clock vs. Bedtime | |
|---|---|---|---|---|---|---|---|---|---|
| | Average of all of the interval measurements | Average of three measurements at 2:00, 3:00, and 4:00 a.m. | Average of three measurements at 2, 3, and 4 h after going to bed | Difference | *P* | Difference | *P* | Difference | *P* |
| Number of measurements per night | 7.4 ± 1.3 | 2.8 ± 0.5 | 3.0 | | | | | | |
| Systolic BP, mmHg | 116.4 ± 12.3 | 115.8 ± 13.4 | 113.1 ± 14.1 | −0.5 ± 5.5 | .337 | −3.3 ± 5.0 | <.001 | 2.7 ± 8.2 | .002 |
| Diastolic BP, mmHg | 67.1 ± 8.0 | 66.8 ± 8.0 | 65.0 ± 9.4 | −0.2 ± 3.7 | .530 | −2.1 ± 3.6 | <.001 | 1.9 ± 5.1 | <.001 |
| Heart rate, bpm | 60.7 ± 6.6 | 59.9 ± 6.7 | 61.4 ± 6.9 | −0.8 ± 2.7 | .007 | 0.7 ± 2.2 | .001 | −1.5 ± 3.7 | <.001 |

*Note:* Values are mean ± SD.

Abbreviation: BP, blood pressure.

disturbance (average of 0.8–1.4 times of awakening per night) was reported during the present hourly BP measurements.[10] If only a wrist device were worn, discomfort and sleep disturbance would be further reduced. In addition, a lower frequency of nighttime measurements would be more acceptable for many people who need to repeatedly monitor their BP during sleep for a long period.

Regarding the BP values, the clock-based average of the three measurements in the present study was comparable to the average of all of the 60-min interval measurements (mean 7.4 ± 1.3 readings), and the bedtime-based average of the three measurements was significantly lower. Our results indicate that the measurement of only three clock-based wrist BP values can provide reliable values for the evaluation of nighttime BP.

The majority of nighttime home BP monitoring schedules using an upper-arm device used measurements at 2:00, 3:00, and 4:00 a.m. or measurements at 2, 3, and 4 h after bedtime.[4] Fujiwara et al assessed the reliability of two different nighttime home BP measurement schedules: clock-based measurements at 2:00, 3:00, and 4:00 a.m. and bedtime-based measurements at 2, 3, and 4 h after bedtime.[13] The agreement between the average value of the first night and the second night showed moderate-to-major, and there was no significant difference in the reliability between clock-based and bedtime-based measurements. Kollias et al demonstrated that three measurements at 2, 3, and 4 h after bedtime for two nights (total six readings) gave reasonable agreement with the average of nighttime BP values measured by ABPM and was related to preclinical organ damage.[14] In the J-HOP study in which measured nighttime BP at 2:00, 3:00, and 4:00 a.m., the average of nighttime home SBP values was slightly higher (2.6 mmHg) than that of nighttime ambulatory SBP values, and the relationship between hypertensive target organ damage and nighttime home SBP was stronger than that for nighttime ambulatory SBP.[6]

The J-HOP study also revealed an association between nighttime home BP and prognosis. Nighttime home SBP was a predictor of incident cardiovascular events, independent of office SBP and morning home SBP measurement.[8] Another J-HOP analysis demonstrated a significant association between future cardiovascular events and nocturnal hypertension detected by HBPM (nighttime BP measured at 2:00, 3:00, and 4:00 a.m.) but not with nocturnal hypertension detected by ABPM.[15]

The aforementioned studies used an upper-arm device to measure nighttime home BP. The present study is the first to compare nighttime BP measurement schedule using a wrist-worn nocturnal HBPM device. In this series of 50 hypertensive patients with antihypertensive treatment, the average of the clock-based measurements were similar to the ABPM-like average of interval measurements throughout a night; however, our results might not apply to other populations.

### 4.3 | Nighttime BP measurement and sleep duration and timing

In cases in which an individual's sleep time is at 0:00 a.m., clock-based measurements at 2:00, 3:00, and 4:00 a.m. and bedtime-based measurements at 2, 3, and 4 h after bedtime are consistent. For a patient who goes to sleep early, the clock-based and bedtime-based measurements would assess BP at different time points. Our present results revealed that there was no significant difference in the SBP values between the clock-based and bedtime-based measurements regardless of the sleep duration, early sleep, and early waking; however, our sample sizes in each of these groups were too small to generalize the results.

A recent study revealed that irregular sleep durations and irregular timing may be risk factors for cardiovascular disease, independent of traditional cardiovascular risk factors and sleep quantity and/or quality.[16] The clock-based measurement may be an index more closely related to cardiovascular risk because it captures BP at different time points after going to bed. However, we have no data to assess cardiovascular risk and organ damage in this study. Further investigations are needed to evaluate the prognostic power of nighttime BP measurement indices.

Our patients were relatively elderly and seemed to have sufficient sleep durations (average 7.7 h). Our results might not be adaptable for short sleepers and those who sleep very late or have irregular sleep habits. In consideration of these sleep features, a combination of both schedules (eg, at 2:00, 3:00, and 4:00 a.m. and 4 h after bedtime) might be widely acceptable for any population.

### 4.4 | Study limitations

There are several possible limitations to our study. The number of participants was small (n = 50), and we assessed only two nights of BP readings. All of the participants were outpatients at one hospital (Jichi Medical University Hospital); we did not obtain data from a variety of people with different lifestyles, environments, and ethnicities, and it is thus unclear whether our results can be generalized to other populations. In addition, we did not collect data to evaluate organ damage or cardiovascular events. Further prognostic studies with larger populations are needed to establish the optimal nighttime home BP measurement schedule for wrist BP monitoring.

## 5 | CONCLUSION AND PERSPECTIVES

In 50 hypertensive patients, compared to the average of all of the 60-min interval measurements, the average of wrist BP values measured at the three time points of 2:00, 3:00, and 4:00 a.m. was comparable whereas the average of the three wrist BP values measured at 2, 3, and 4 h after the participants went to bed was significantly lower. Our findings indicate that nighttime measurements of BP at three clock-based time points per night by a wrist nocturnal HBPM device can provide reliable values. However, further studies with larger populations are required for the confirmation of the optimal nighttime BP measurement schedule.

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## CONFLICT OF INTEREST

K. Kario has received research grants from Omron Healthcare, A&D, and Fukuda Denshi.

## AUTHOR CONTRIBUTIONS

K. Kario supervised the conduct of the study and data analysis, and had the primary responsibility of writing this paper. N. Tomitani analyzed the data and wrote the Introduction, Methods, Results, and Discussion sections. H. Kanegae contributed to the analysis.

All authors discussed the results and contributed to the final manuscript.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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