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What is the optimal interval between successive home blood pressure readings using an automated oscillometric device?

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Abstract

Objectives—To clarify whether a shorter interval between three successive home blood pressure (HBP) readings (10 s vs. 1 min) taken twice a day gives a better prediction of the average 24-h BP and better patient compliance.

Design—We enrolled 56 patients from a hypertension clinic (mean age: 60 ±14 years; 54% female patients). The study consisted of three clinic visits, with two 4-week periods of self-monitoring of HBP between them, and a 24-h ambulatory BP monitoring at the second visit. Using a crossover design, with order randomized, the oscillometric HBP device (HEM-5001) could be programmed to take three consecutive readings at either 10-s or 1-min intervals, each of which was done for 4 weeks. Patients were asked to measure three HBP readings in the morning and evening. All the readings were stored in the memory of the monitors.

Results—The analyses were performed using the second–third HBP readings. The average systolic BP/diastolic BP for the 10-s and 1-min intervals at home were 136.1 ±15.8/77.5 ±9.5 and 133.2 ±15.5/76.9 ±9.3 mmHg (P = 0.001/0.19 for the differences in systolic BP and diastolic BP), respectively. The 1-min BP readings were significantly closer to the average of awake ambulatory BP (131 ±14/79 ±10 mmHg) than the 10-s interval readings. There was no significant difference in patients' compliance in taking adequate numbers of readings at the different time intervals.

Conclusion—The 1-min interval between HBP readings gave a closer agreement with the daytime average BP than the 10-s interval.

Keywords

ambulatory BP monitoring; home BP; measurement interval; multiple BP measurements

Introduction

Home blood pressure (HBP) measurement is increasingly used in clinical practice. A number of studies and reviews [1] have demonstrated that home BP is superior to clinic BP in its reproducibility [2–4], for predicting target organ damage [5–7] and future cardiovascular

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events in general populations [8,9], hypertensive patients [10], and patients with kidney disease [11]. The international BP guidelines for the use of home BP [12–14] have stated that when a series of readings is taken, a minimum of two readings should be taken at intervals of at least 1 min, and the average of those readings should be used to represent the patient's blood pressure.

Most of the currently available home monitors take only one reading when the device is triggered, but the latest generation of monitors will take multiple readings automatically at fixed intervals. However, doing this will take longer than taking a single reading, raising the possibility that compliance with the procedure will be less. Although an interval of 1 min between readings has been recommended, there is some evidence that an interval of less than 15 s may be as accurate as the conventional 1-min interval [15,16]. However, these studies were performed in clinical settings by trained research staff. Alternatively, there is the possibility that taking multiple BP measurements at shorter intervals is less accurate because of hyperemia of the upper arm [17], which has been investigated during measurements made with the Korotkoff method, and this may be the source of the recommendation to wait at least 1 min between measurements. In addition, it has been observed that there is a progressive fall of BP with multiple readings, the extent of which varies according to the interval between successive readings. At the present time, there have been no studies comparing the feasibility and accuracy of short time intervals with the more conventional 1-min interval for readings taken by oscillometric home monitors. We performed this study to test the hypotheses that repeated oscillometric home BP measurement using 10-s intervals are as accurate as those using the conventional 1-min intervals; and patient compliance is better when 10-s intervals are used.

Methods

Patients were recruited from the hypertension clinic at Columbia University New York-Presbyterian Hospital. The inclusion criteria were a diagnosis of known or suspected hypertension, and, if treated, having been on a stable dose of medication for at least 1 month with no plan to change treatment for the next 2 months. Forty-two out of 56 patients were taking antihypertensive medications. Patients with major arrhythmias or with arm circumference greater than 40 cm were excluded. The following variables were assessed at the initial visit: age, sex, race, body mass index, history of cardiovascular disease, and handedness. Arm circumference was measured, and the appropriate cuff size was selected [12].

Clinic BP measurements

Clinic BP was measured at baseline and at the 4th and 8th week visits. Patients sat quietly with their backs supported, without crossing their legs, and with both arms supported at heart level for 5 min before the measurements were made. Clinic BP was measured with auscultation by a physician (three readings) using a mercury sphygmomanometer and by an automated BP monitor [Omron HEM-5001 (Kyoto, Japan), the home monitor used in the study] with three readings at 1 min intervals, giving a total of six clinic readings at each visit. The sequence of the clinic BP measurements was randomly assigned at each visit. Thus, each of the two types of clinic BP measurements used in the analysis described below was based on the average of nine readings (three on three occasions over an 8-week period) taken under rigorously standardized conditions.

Home BP measurement

The HBP monitor used for this study was an Omron HEM-5001 device, which can be set to automatically take three readings, at either 10-s or 1-min intervals. Although this device has not been subjected to a formal validation test, it uses the same algorithm as the HEM-737,

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which has passed the Association for the Advancement of Medical Instrumentation (AAMI) validation protocol [18]. Patients were given a HBP monitor and instructed in its use. They were instructed to measure home BP after a 5 min rest. It was preset by the investigators to take three readings at either 10-s or 1-min intervals, based on random assignment, for the initial 4-week home monitoring period. The 1-min (or 10-s) interval was between the end of the first reading and the start of the next reading. They were asked to measure morning HBP and evening HBP on at least 4 days/week for 8 weeks. The measurement results (date, time, BP, and pulse rate) were automatically stored in the memory of the monitor. Patients were asked to visit the investigator’s office at the 4th and 8th week and bring the monitor, at which times the data were uploaded to a computer. At the 4th week visit, the interval setting of the home monitor was changed by the research staff from 1 min to 10 s (H1 group) or from 10 s to 1 min (H2 group).

Ambulatory BP measurement

Ambulatory BP (ABP) measurement over 24 h was performed at the second visit. Patients were asked to keep a diary that included the time of going to bed, waking-up, meals, and other events. ABP monitoring was performed with a Spacelabs 90207 device (SpaceLabs Medical, Inc., Redmond, Washington, USA). Blood pressure was measured every 15 min between 0700 and 2300 h and every 30 min during the night. Patients were asked to send the device and diary back to the investigator’s office after completion of ABP monitoring. The average awake and sleep ABP value were calculated based on the patients’ diaries. This study was approved by the Institutional Review Board of Columbia University, and written informed consent was obtained from all participants.

Statistical analyses

We used the mean of the first–second, second–third, and the first–third readings for the analyses of the home BPs. BP readings labeled as ‘morning’ and ‘evening’ were used as morning and evening readings, but BP measurements taken at other times were excluded from the analyses. The averages and the differences between home BP readings taken at 10-s and 1-min intervals were compared using paired *t*-tests. Morning and evening BP readings were combined when 10-s and 1-min intervals were compared and when home BP was compared with clinic BP or ABP measures. The associations between home BP, clinic BP and ABP were compared using the intraclass correlation coefficient (ICC) for agreement [19]. For all analyses, a significance level of *P* value less than 0.05, two-tailed, was used. The preliminary data processing of the HBP and ABP data was performed in SAS 9.1 (SAS Institute, Research Triangle, North Carolina, USA). All statistical analyses were performed with SPSS, 13.0 (SPSS, Inc., Chicago, Illinois, USA).

Results

Initially, 57 consecutive patients seen in the hypertension clinic were enrolled for the study. Because one patient withdrew from the study at the second visit, 56 patients completed the study protocol. As shown in Table 1, the mean age of the patients was 60 years, two-thirds were White, and 75% were on antihypertensive treatment. Office BP level measured by the HEM-5001 (131 ±15/76 ±9 mmHg) was similar to awake BP (131 ± 14/79 ±10 mmHg), but home BP average (135 ±15/77 ±9 mmHg) calculated by both 10 and 1-min intervals) was higher than office and awake ABP. The average of all three successive readings (first to third), across morning and evening assessments, was 136/78 mmHg, the average of the first and second readings was 137/78 mmHg, and the average of the second and third readings was 135/77 mmHg when they were calculated by the average of both measurement intervals. Figure 1 shows the differences among the three consecutive home systolic BP readings in the morning, separately for the data assessed at 10-s and 1-min intervals. At both sampling intervals, the

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second readings were significantly lower than the first readings, and the third readings were significantly lower than the first and the second readings. The similar trends were observed for morning diastolic BP (DBP) and evening systolic BP (SBP)/DBP.

Bland–Altman plots for the averages of awake ABP and home BP showed that the difference between awake and home SBP/DBP was similarly distributed across the BP range for both the 10-s and 1-min intervals and was less than 20 mmHg for all but one participant (data are not shown).

Table 2 shows the average home BP levels, the differences from home BP to ambulatory awake BP, and the differences between the first and second, or the second and third readings. All of the data are combined BP measurements of morning and evening. As shown, the average SBPs measured at 10-s intervals were consistently higher than those measured at 1-min intervals. The values of readings averaged from the first to second were significantly higher than those averaged from the second to third (Table 2a). There were no significant differences in DBP levels between 10-s and 1-min intervals. Table 2(b) shows the comparisons between ABP and home BP readings. The average home BP measured at 10-s and 1-min intervals was consistently higher than the awake SBP, but there were no significant differences between the home BP averages of the second–third readings taken at 1-min intervals and the awake SBP. These differences between home SBP and ambulatory awake SBP were significantly higher in the 10-s intervals. The intraclass correlations of agreement between 10-s and 1-min intervals of the home BP and awake SBP were 0.712/0.725 for SBP and 0.693/0.673 for DBP when two readings of the home BP were used each time. Table 2(c) shows the comparisons of the first vs. second and second vs. third readings taken at 10-s vs. 1-min intervals for the home BPs. The differences between the first and second readings were significantly larger in 1-min intervals than in the 10-s intervals. The differences between the second and third readings were significantly larger when the interval between them was 10-s than when it was 1-min, for both systolic and diastolic BP.

Automated measurement of clinic BP

Additionally, we compared the clinic measurement of HEM-5001 and mercury sphygmomanometer. The average BP levels were 129 ± 15/77 ± 10 mmHg when taken by the mercury sphygmomanometer and 131 ± 15/76 ± 9 mmHg for the HEM-5001. The interclass correlations of agreement between mercury readings and HEM-5001 were 0.953 for SBP and 0.906 for DBP when three readings were taken each time.

Patient compliance

Compliance was measured as the number of each set of home BP readings taken per week. The numbers of occasions per week that three measurements were taken in the morning were 5.2 ± 1.2 days for the reading taken with 10-s intervals and 5.3 ± 1.4 days for the 1-min intervals ($P = 0.91$). There were no differences in the evening BP readings. So, the difference in compliance between the two measurement intervals was negligible (and not statistically significant).

Discussion

This study has shown that BP readings of a 10-s interval of multiple home BP measurements were higher than readings taken using the conventional 1-min interval. The 1-min interval of three measurements tended to give a better estimate of the average daytime BP level, and, therefore, the 1-min interval would be better for clinical use. This is the first study testing the validity of using very short time intervals between BP measurements made at home.

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The validity of using very short intervals between oscillometric BP measurements in the clinic has been reported by two groups. Yarows *et al.* [15] reported that a 15-s interval between BP measurements was as accurate as a 1-min interval in normotensive volunteers. Koehler *et al.* [16] showed that multiple BPs measured over a period of 10–15 s were similar to those taken at 1-min intervals using a sphygmomanometer and automatic devices (which were not cited as validated). Our results are consistent with these reports, but the previous studies were performed only in clinical settings because home monitors with preset measurement intervals were not available. In contrast, with the advent of new technology, we have been able to examine the results of using two different and standardized measurement intervals for readings taken at home. We used the awake ABP as the comparator measure and also compared the home readings with readings taken in the clinic under standardized conditions using both mercury sphygmomanometer readings and automated device readings. The main finding of the study was that though the intraclass correlations of agreement for the 10-s and 1-min intervals at home with awake ABP were similar, the mean SBP levels taken at 10-s intervals were significantly higher than SBP taken at 1-min intervals, and the average home BP with 1-min intervals was closer to the daytime ABP. Because the BP measurements of 10-s and 1-min intervals were done in the same patients crossed over, the baseline BP level was similar, and arm size, cuff size, and deflation time were exactly the same for the two measurement conditions. Therefore, we do not think that these factors affected the differences between the 10-s and 1-min interval measurements.

The differences between the first and the second readings were larger for 1-min intervals than for 10-s intervals, and, conversely, the difference of the second and the third readings were larger for 10-s intervals than for 1-min intervals. Recent home BP guidelines have stated that the average of the first and second readings should be used for clinical practice [13,14], but taking the average SBP of the second and third readings may best predict the awake SBP [20]. It should be pointed out that the device we used had a relatively rapid inflation and deflation, and our findings do not necessarily apply to all other devices. There has hitherto been little investigation into how long the intervals between measurements should be [15,16]. Hypertension guidelines have empirically recommended to wait for 1 or 2 min for the next measurement, which has been used for the Korotkoff technique [12]. Brook [21] has reported that the accuracy of HBP measurements, as determined by their agreements with awake ABP, is similar regardless of substantial variations in HBP monitoring schedules, though the measurement interval issue was not discussed. Many of the patients in the present study could have started their measurements right after some activities without resting a few minutes. Consequently, their BP stabilized a few minutes after beginning the measurements. Namely, the second and the third readings of the 1-min interval might have been measured in more stable conditions than in the second and the third readings of the 10-s intervals during which the BP was still going down. For keeping patients' rest, three successive measurements of 1-min intervals would be better choice in clinical practice. Our results can lead to a conclusion that the 1-min measurement interval is preferable to the 10-s interval for home BP measurement.

Accuracy of the HEM-5001

In the office BP measurement procedure, we compared the HEM-5001 with a mercury sphygmomanometer. The average office BP level taken by the HEM-5001 was very similar to office BP taken by a mercury manometer. The intraclass correlations of agreement in the HEM-5001 and mercury readings were excellent for both SBP and DBP. This is not an official validation study, but the HEM-5001 appears to be as accurate as a mercury sphygmomanometer.

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Rationale for taking a 1-min interval between readings

In the American Heart Association BP measurement guideline [12], the following statement was described without any citation: 'three readings should be taken in succession, separated by at least 1 min. The first is typically the highest, and the average should be used as the blood pressure reading.' The rationale for taking 1 min intervals between multiple measurements appears arbitrary. Venous congestion or hyperemia has traditionally been thought to affect the BP measurement results when the Korotkoff method is used, but in recent reports, very short time intervals between readings did not produce different values from conventional intervals when oscillometric devices were used [15,16]. Ischemia in an arm distal to the measurement cuff can lower the recorded BP by 5–15 mmHg if the ischemia is maintained at 20 mmHg above the systolic BP for 90 s, but it raises the BP much less if the ischemia is maintained for only 30 s [22]. As the proper technique is to inflate the cuff to 20 mmHg above the SBP and use a deflation rate of 2 mmHg/s, the ischemia from total occlusion of the cuff should only last 10 s, and is thus unlikely to change the measurement of the BP.

Compliance

The compliance measure was, unexpectedly, not statistically different between the 10-s and 1-min intervals of BP measurement. We asked patients to measure their BP on as many days as possible and at least 4 days/week. Because the patients in this study were from a hypertension clinic that usually recommends that patients measure their home BP, the majority of them were used to taking frequent readings. However, if we had recruited patients who had never measured home BP, there might have been a difference in compliance between the 10-s and 1-min intervals, especially in the mornings when time is often most pressing. A further study may be needed to resolve this issue.

Study limitations

In this study, average daytime ABP (131/79 mmHg) was equal to office BP (131/76 mmHg), and home BP (135/77 mmHg using 1 min intervals and the average of morning and evening readings) was higher than office BP. The reason for the lower level of office BP than home BP was that office BP was measured in the standard condition following the international guidelines after at least 5-min rest; measured by a research assistant (but a physician in Japan) rather than by a doctor and multiple measurements (more than 6 readings) were taken in one occasion after seeing a doctor. The BP levels in the normal range were another reason for the relatively lower level of office BP as was reported in previous studies which have shown that office BP was the same or lower than the out-of-office BP when they were in normotensive range [23–26]. The use of large adult cuff ($N = 8$) may be another limitation of this study because the time of inflation and deflation is different from that of regular size cuff.

Conclusion

Although both the 10-s and 1-min intervals between three successive home BP readings taken both in the morning and evening showed good correlations with the daytime average BP taken by ambulatory monitoring, and no difference in patient compliance taking the readings, the 1-min intervals gave average home BP levels that were closer to the daytime ABP and would therefore be recommended as optimal.

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Abbreviations

AAMI	the Association for the Advancement of Medical Instrumentation
ABP	Ambulatory BP
ABPM	ambulatory BP monitoring
DBP	diastolic blood pressure
HBP	home BP
ICC	intraclass correlation coefficient
SBP	systolic blood pressure

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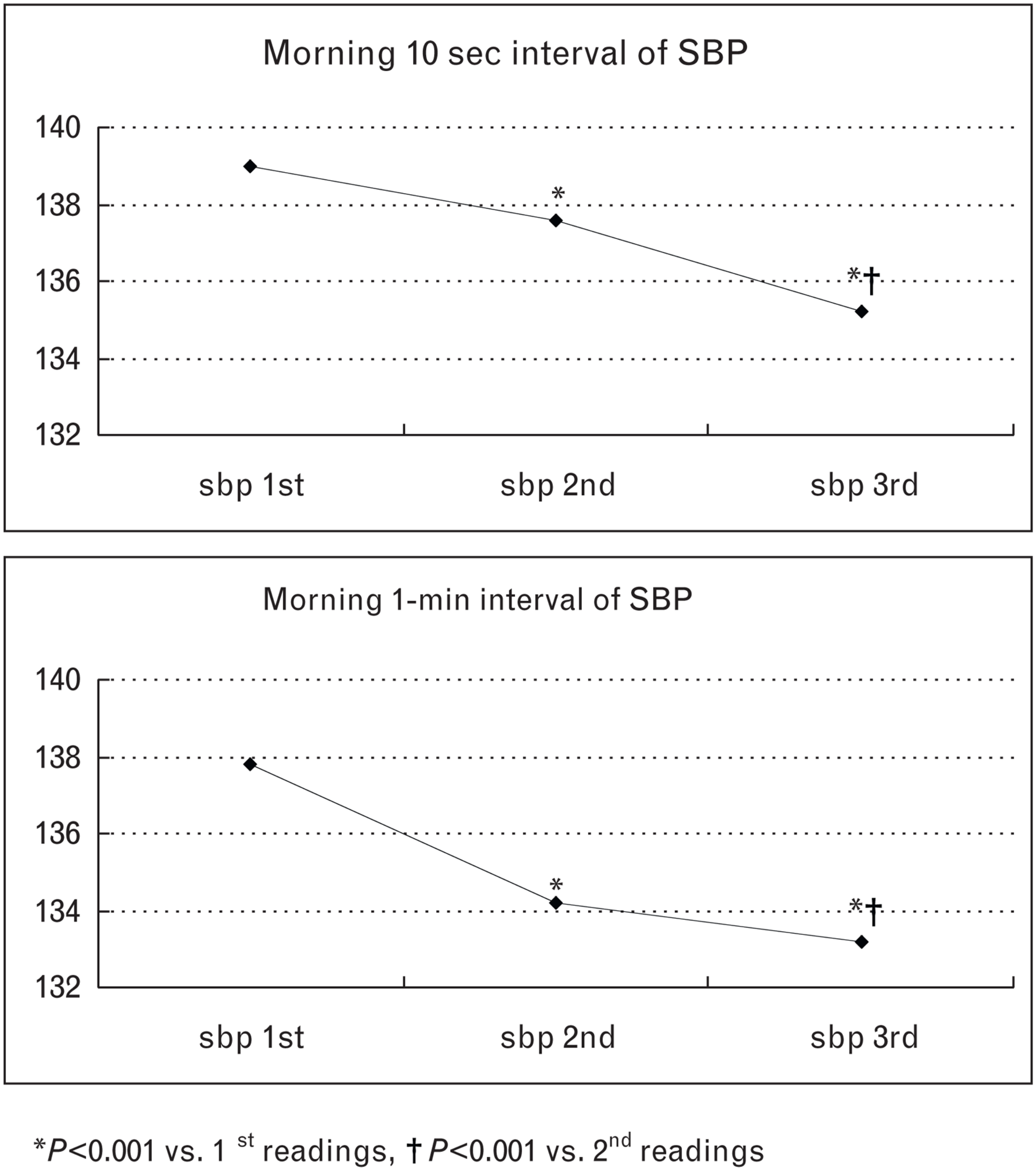

Fig. 1.

Changes of morning BP by measurement times and a comparison of home systolic BP in the morning across three consecutive readings taken at 10-s vs. 1-min intervals. **P* <0.001 vs. first readings, †*P* <0.001 vs. second readings.

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Table 1

Baseline characteristics

Variables	Average or percentage
Number of patients	56
Age (years)	60.0 ±14.4
Sex [number (%) of men]	26 (46.4%)
White race (%)	34 (60.7%)
Body mass index (kg/m^2)	26.6 ± 6.4
Diagnosed hypertension (%)	51 (91.1%)
History of hypertension (years)	8.3 ± 9.1
On antihypertensive treatments (%)	42 (75%)
Type II diabetes (%)	3 (5.4%)
History of cardiovascular disease[a] (%)	8 (14.3%)
Patients with large adult cuff (%)	8 (14.3%)

Data are shown as mean ± SD or percentages.

[a]Cardiovascular disease includes stroke, heart attack, angina, coronary bypass surgery, or coronary angioplasty.

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Table 2

Comparison between home BP readings taken at 10-s and 1-min intervals

	10-s intervals	1-min intervals	*P*
(a) Average home BP levels			
First–third SBP (mmHg)	137.0 ± 15.6	134.7 ± 15.4	0.005
First–third DBP (mmHg)	77.9 ± 9.4	77.2 ± 9.1	0.15
First–second SBP (mmHg)	138.0 ± 15.5††	135.6 ± 15.4††	0.005
First–second DBP (mmHg)	78.2 ± 9.4††	77.4 ± 9.2†	0.07
Second–third SBP (mmHg)	136.1 ± 15.8	133.2 ± 15.5	0.001
Second–third DBP (mmHg)	77.5 ± 9.5	76.9 ± 9.3	0.19
(b) Differences from home BP to awake SBP/DBP			
First–third SBP (mmHg)	6.0 ± 10.4***	3.7 ± 10.7*	0.005
First–third DBP (mmHg)	−1.2 ± 7.7	−1.9 ± 7.6	0.15
First–second SBP (mmHg)	7.0 ± 10.4***	4.6 ± 10.7**	0.005
First–second DBP (mmHg)	−0.9 ± 7.7	−1.8 ± 7.6	0.07
Second–third SBP (mmHg)	5.1 ± 10.5**	2.2 ± 10.9	<0.001
Second–third DBP (mmHg)	−1.6 ± 7.7	−2.2 ± 7.8	0.19
(c) Differences from first to second or second to third readings			
First minus second SBP	1.4 ± 2.5 (4)	3.7 ± 3.2 (16)	<0.001
First minus second DBP	0.7 ± 1.8 (0)	0.7 ± 1.7 (1)	0.99
Second minus third SBP	2.3 ± 1.5 (3)	1.2 ± 1.4 (1)	<0.001
Second minus third DBP	0.7 ± 0.9 (0)	0.2 ± 0.9 (0)	0.002

Numbers in parentheses indicate the number of patients whose differences in pressure ≥5 mmHg. *P* values are comparisons between 10-s vs. 1-min intervals.

* P <0.05,

** P <0.01,

*** P <0.001 vs. awake SBP.

† P <0.01,

†† P <0.001 vs. second–third SBP/DBP of the same intervals.