Optimal Schedule for Home Blood Pressure Measurement Based on Prognostic Data

The Finn-Home Study

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Abstract—Current guidelines based on cross-sectional statistical parameters derived from reference populations make equivocal recommendations for the optimal schedule of home blood pressure (BP) measurement. The objective of this study was to determine a schedule for home BP measurements in relation to their predictive value for total cardiovascular risk. Home BP was measured twice every morning and evening for 1 week in an unselected nationwide population of 2081 subjects aged 45 to 74 years. The prognostic significance of BP for fatal and nonfatal cardiovascular events was examined using adjusted Cox proportional hazards regression models. A total of 162 cardiovascular events were recorded during a 6.8-year follow-up. The predictive value of home BP increased progressively with the number of measurements, showing the highest predictive value with the average of all measurements (systolic/diastolic hazard ratio per 1-mm Hg increase in BP: 1.021/1.034; systolic/diastolic 95% CI: 1.012 to 1.030/1.018 to 1.049). However, most of this increase was achieved during the first 3 days of measurement (hazard ratio: 1.017/1.028; 95% CI: 1.009 to 1.026/1.013 to 1.045), and only minimal increase occurred after day 6. No additional benefit was achieved by discarding the values obtained during the first day of measurement. Morning and evening BPs were equally predictive of future cardiovascular events. Novel prognostic data from this study show that measurement of home BP twice in the morning and evening, preferably for a period of 7 days, or for at least 3 days, provides a thorough image of a patient's BP level. This information should be used to prepare a unified international guideline for home BP measurement. **(*Hypertension*. 2011;57:1081-1086.)**

Key Words: hypertension ■ blood pressure measurement ■ home blood pressure measurement ■ epidemiology ■ guidelines

Hypertension, one of the most important challenges facing public healthcare worldwide, cannot be prevented, detected, treated, or controlled without accurate and practical methods for blood pressure (BP) measurement.[1] During the past decade, the popularity of home BP measurement has exploded as small, easily, and reliably operated automatic devices have been introduced to the market.[2,3] In addition to its ease of use compared with other methods of measurement, home BP measurement also seems to have medical advantages, because it is free from the white-coat effect, and seems to have a stronger predictive power for future cardiovascular events than office BP.[4]

Despite the popularity and advantages of home BP measurement, no consensus exists on how many daily measurements and for how many days it should be performed when measuring BP at home to obtain the best assessment of the actual BP levels in a given subject. A great deal of conflict exists in the recommended home BP measurement schedules in various international guidelines, which only demonstrates that no agreement on this matter has yet been reached (Table 1).[5–7]

Part of the problem arises from the fact that current recommendations for self-monitoring of BP by patients at home mainly rely on statistical parameters derived from reference populations instead of outcome data.[8] Previous studies have tried to determine the best schedule for home BP measurement based on the following: (1) the reproducibility of home BP values obtained; (2) their stability over time; and (3) their relation to the average ambulatory BP values, the latter being considered the gold-standard references.[7,9,10] We have also tried previously to determine the optimal home BP monitoring schedule by comparing the correlations of different BP indices with indicators of target organ damage.[11]

Prognostic clinical data are, of course, a more suitable method than statistical methods for defining the best schedule for home BP measurement. Recent follow-up studies have already shown that even 2 home BP measurements are able to

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Table 1. Proposals for Home Blood Pressure Measurement Schedule by Various Guidelines

Guideline	No. of Measurements on Each Occasion	No. of Days	Morning and Evening Measurements	Other
European[7]	2	7	Yes	Discard first-day values
American[6]	3	NA	Yes	
Japanese[5]	1 (−3)	5–7	Yes	

NA indicates not available.

predict the risk of cardiovascular events,[12,13] but so far only 1 study by Ohkubo et al[14] has tried to identify the amount of home BP measurements needed based on prognostic data. The authors of this study reported that the predictive value for the risk of stroke increases progressively without any threshold if the number of measurements was increased from 1 to 14. However, the value of this study is limited by several key points. This was a study based in a single rural community, and no evening or duplicate measurements were performed, although the prognostic value of evening measurements has later been published by Asayama et al.[15] In addition, incidence of stroke was the only end point in this study, and no other cardiovascular end points were available.

The optimal schedule for home BP measurement based on total cardiovascular risk is unknown. The objective of this study was to determine the optimal schedule for home BP measurements in relation to their predictive value for total cardiovascular risk in an unselected nationwide population sample using an up-to-date home-monitoring scheme.

Methods

Subjects

The study sample was drawn from the participants of a multidisciplinary epidemiological survey, the Health 2000 Study, which was carried out in Finland from the fall of 2000 to the spring of 2001. The study population was a stratified 2-stage cluster sample of 8028 subjects drawn from the population register to represent Finnish adults aged ≥30 years. The stratification and sampling procedures have been described previously in detail.[16,17]

Of the subjects aged 45 to 74 years (n=4388), 84% (n=3672) agreed to participate in the interview and attended the health examination. A total of 2106 subjects also participated in the home BP measurement substudy (Finn-Home Study). Home measurement of BP was not performed on all of the subjects willing to participate because of the limited number of home monitors (≈800), and study subjects were selected on the basis of monitor availability. The characteristics of the study population are identical to the general Finnish population aged 45 to 74 years, as reported previously.[16] Subjects who had missing laboratory or health examination data (n=25) were excluded from the study, and the final study population consisted of 2081 subjects aged 45 to 74 years.

The study protocol of the Health 2000 Survey was approved by the epidemiology ethics committee of the Helsinki and Uusimaa hospital region. All of the participants gave signed informed consent.

Flow of the Study

At an initial health interview at the subject's home, basic background and sociodemographic information, information about health and illnesses, and information about the use of medication were gathered by centrally trained interviewers. Participants of the home measurement substudy then received home monitors for measuring BP during the week after the health interview. Home BP was measured twice every morning and evening for 7 consecutive days using an up-to-date monitoring scheme and a validated home monitor.[18] The subjects kept a record of all readings in a logbook. A physical examination was performed on each subject 1 to 6 weeks later at a local health center by centrally trained doctors and nurses. Each subject's height, weight, and office BP (2 measurements) were measured, and fasting blood samples for serum lipids and glucose were taken. Details of the methodology of the project have been published elsewhere.[16,17]

Follow-Up

Follow-up data were accumulated until December 31, 2007. Mortality data were obtained from the national mortality register based on death certificates. Data on hospitalization attributed to heart failure and nonfatal coronary and stroke events were obtained from the national hospital discharge register. In addition, information on performed percutaneous coronary interventions and coronary artery bypass graft surgery was obtained from the hospital discharge register. Details of the follow-up phase have been published previously.[4]

The primary end point was the combination of cardiovascular mortality, nonfatal myocardial infarction, nonfatal stroke, hospitalization for heart failure, percutaneous coronary intervention, and coronary artery bypass graft surgery. Only the first event was included in this analysis.

Statistical Analyses

We used Cox proportional hazard models for multivariate analyses. Association of home BP with the end points was analyzed by estimation of the hazard ratios and their 95% CIs per 1-mm Hg increase in BP. The models were adjusted for sex, age, use of antihypertensive medication, past history of cardiovascular disease (history of stroke, heart failure, or ischemic heart disease), smoking status (daily use of tobacco products), presence of diabetes mellitus (fasting serum glucose level ≥7.0 mmol/L and/or a history of use of oral hypoglycemic agents or insulin injection), and presence of hypercholesterolemia (fasting serum total cholesterol level of ≥7.0 mmol/L and/or use of statins). The likelihood ratio χ^2 value was used as a measure of the improvement of goodness of fit between the model containing a single BP index and the model containing 2 indices. A significant likelihood ratio χ^2 indicates that the index represents a significantly stronger association with cardiovascular events. BP variables were compared using the Student *t* test. A *P* value <0.05 was considered statistically significant. Data are reported as mean±SD. Database management and statistical analysis were performed with SAS software (SAS Institute, Cary, NC), version 9.1.

Results

The population characteristics have been reported previously in detail and are very close to those of the general Finnish population aged 45 to 74 years.[4,16] Mean age was 56.3±8.5 years, and 46.3% were men. Prevalences of smoking, hypercholesterolemia, and diabetes mellitus were 19.6%, 29.6%m and 6.3%, respectively. A total of 22.7% of the subjects were using antihypertensive medication, and 11.0% had experienced a previous cardiovascular event. Office systolic/diastolic BP was significantly higher than home systolic/diastolic BP (137.4±20.2/83.7±10.6 versus 129.8±18.8/80.4±9.5 mm Hg; *P*<0.001 for both). The mean number of measurements was 26.7±3.7 (range: 2.0 to 28.0).

The follow-up period ended on December 31, 2007, and the mean follow-up time was 6.8 years, resulting in 14 081 person-years of follow-up. A total of 162 subjects had ≥1 cardiovascular event (incidence: 11.5/1000 person-years) during the follow-up period. The origins of these events have been reported previously.[4]

Table 2. Mean Home BP Values

BP	BP Parameter	Total (n=2081)	Fatal and Nonfatal CV Events: Yes (n=162)	Fatal and Nonfatal CV Events: No (n=1919)
Systolic	1st morning	131.6 (22.0)	145.0 (23.8)	130.5 (21.5)
	1-d	133.0 (20.8)	145.6 (21.6)	131.9 (20.4)
	2-d	131.7 (20.0)	144.6 (20.1)	130.7 (19.6)
	Days 2 to 7	129.3 (18.7)	142.1 (19.3)	128.2 (18.3)
	1-wk	129.8 (18.8)	142.7 (19.4)	128.7 (18.3)
	Morning	128.1 (19.6)	141.7 (19.9)	127.0 (19.1)
	Evening	131.4 (18.9)	143.6 (20.2)	130.4 (18.4)
	First measurement	131.3 (19.2)	144.2 (19.5)	130.2 (18.7)
	Second measurement	128.2 (18.6)	141.6 (19.8)	127.1 (18.1)
	Days 1.0 to 3.5	130.5 (19.4)	143.4 (19.3)	129.4 (19.1)
Diastolic	1st morning	81.8 (11.4)	85.5 (11.7)	81.5 (11.3)
	1-d	81.8 (10.5)	85.2 (10.6)	81.5 (10.5)
	2-d	81.2 (10.0)	85.0 (10.1)	80.9 (10.0)
	Days 2 to 7	80.1 (9.4)	84.3 (9.7)	79.7 (9.3)
	1-wk	80.4 (9.5)	84.5 (9.7)	80.0 (9.4)
	Morning	80.3 (10.0)	84.9 (10.3)	80.0 (9.9)
	Evening	80.4 (9.6)	84.0 (10.0)	80.1 (9.5)
	First measurement	81.0 (9.6)	85.2 (9.5)	80.6 (9.5)
	Second measurement	79.7 (9.6)	83.7 (10.3)	79.4 (9.4)
	Days 1.0 to 3.5	80.8 (9.8)	84.7 (10.0)	80.5 (9.7)

All differences in BP values between those who did and did not have a cardiovascular event were significant ($P<0.001$). CV indicates cardiovascular; BP, blood pressure.

Home BP decreased slightly but significantly during the 7 days of measurement. However, most of this decrease in BP occurred between the first and second days of measurement, as reported in Table 2 and in a previous publication.[16] Subjects who had experienced a cardiovascular event during the follow-up had significantly higher mean home BPs obtained during the morning of the first measurement day (1-morning, number of measurements: 2), the first measurement day (1-day, n=4), the first 2 measurement days (2-day, n=8), days 2 to 7 (days 2 to 7, n=24), the whole week (1-week, n=28), the morning measurements (morning, n=14), the evening measurements (evening, n=14), the first measurements of each measurement occasion (first measurement, n=14), the second measurements of each measurement occasion (second measurement, n=14), and all of the measurements during the first 3.5 days (days 1.0 to 3.5, n=14) than those who had not (Table 2; $P<0.001$ for all).

All of the BP variables shown in Figures 1 and 2 were predictive of total cardiovascular risk ($P<0.001$ for all). Figure 1 shows that the predictive value of home BP increased progressively with the cumulative number of measurements, and the greatest predictive value was achieved by using the mean of all of the measurements (systolic/diastolic hazard ratio per 1 mm Hg increase in BP: 1.021/1.034; systolic/diastolic 95% CI: 1.012 to 1.030/1.018 to 1.049). However, most of the increase in predictive value occurred during the first 3 days of measurement (hazard ratio: 1.017/1.028; 95% CI: 1.009 to 1.026/1.013 to 1.045). The predictive value also showed an increasing trend when individual measurement days were analyzed separately, but this trend weakened after the third day of measurement, especially for diastolic BP (Figure 1).

First measurement, second measurement, morning, evening, 7-day, days 2 to 7, and days 1.0 to 3.5 were all predictive of cardiovascular risk ($P<0.001$ for all; Figure 2). Table 3 shows how the likelihood ratio χ^2 values changed when 2 BP indices were analyzed simultaneously. When the first day of measurement was discarded, the predictive ability of the model did not increase. The second measurement on each measurement occasion increased the goodness-of-fit slightly as compared with the model that included only the first measurements, but only with systolic BP. Morning and evening BP had an equally good predictive ability for cardiovascular events (Table 3). We also assessed whether the mean of all measurements performed during the first 3.5 days (days 1.0 to 3.5: 14 measurements) provided additional predictive ability as compared with the first or the second measurements of each measurement occasion (14 measurements for both). Adding the first or second measurement increased the predictive value of the models containing days 1.0 to 3.5, whereas doing the opposite did not. This did not apply for diastolic BP when comparing the second measurement and days 1.0 to 3.5 (Table 3).

Discussion

We have shown in an unselected nationwide population that the predictive value of home BP increases progressively with the number of measurements, showing the highest predictive value with the average of all of the measurements performed during 1 week. However, a clear majority of this increase is achieved during the first 3 days of measurement. No additional benefit in predictive ability is achieved when the values obtained during the first day of measurement are discarded. Morning and evening BPs are equally predictive of future cardiovascular events. Measurement of home BP twice, instead of once, on each measurement occasion offers a marginally better predictive value, because it doubles the number of measurements.

It has been demonstrated previously by Ohkubo et al[14] that the predictive value for stroke risk associated with home BP increases progressively within the range of 1 to 14 measurements performed during 1 week without any clear threshold. Our study, with 28 measurements performed during 1 week, also demonstrates that the predictive value of home BP increases progressively with the number of measurements, showing the highest predictive value with the average of all measurements performed during 1 week. However, a clear majority of this increase is achieved during the first 3 days of measurement, and only minimal increase occurs after day 6. These data confirm our previous cross-sectional findings demonstrating that the correlation between home BP and hypertensive target organ damage increases slightly but steadily over a 1-week home BP measurement period and that

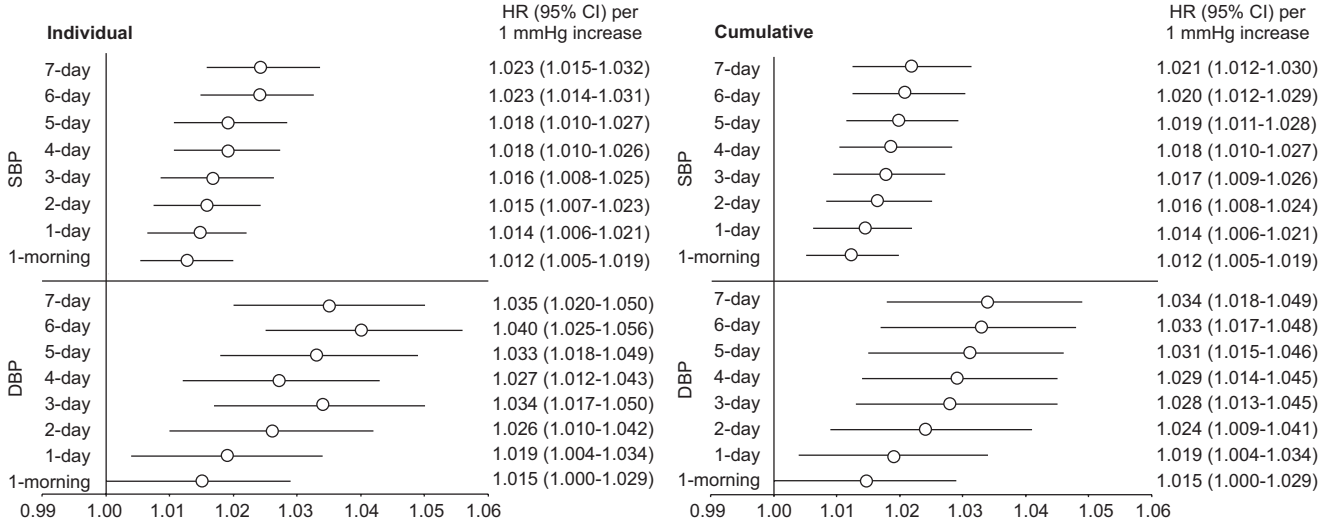

Figure 1. Predictive values of home blood pressures (BPs) on cumulative and individual days of measurement. Hazard ratio (HR) and 95% CI of 1-morning and 1- to 7-day home systolic blood pressure (SBP) and diastolic blood pressure (DBP) levels adjusted for sex, age, use of antihypertensive medication, past history of cardiovascular disease, smoking status, presence of diabetes mellitus, and presence of hypercholesterolemia. Open circles are HR expressed as an increase in cardiovascular event risk per 1-mm Hg elevation of SBP and DBP. Horizontal lines represent 95% CI.

only marginal increase occurs after the sixth day of measurement.[19,20] However, it is not only the number of measurements that is important, because our results also showed that 14 measurements performed on 7 consecutive days seem to provide a slightly better predictive value than 14 measurements performed on the first 3.5 days. Measurement of home BP, preferably for a period of 7 days or for ≥3 days, is, therefore, needed to obtain a thorough image of a patient's true BP level.

The current guidelines recommend from 1 to 3 measurements on each occasion, although the 2 largest epidemiological studies have been performed with just 1 home BP measurement on each occasion.[5–7,12,13] The recommendations of the European and American guidelines are mostly based on the evidence that regression to the mean during consecutive measurements on each occasion is frequently observed, even after long-term monitoring.[21] However, the Japanese Society of Hypertension guidelines for self-monitoring of BP at home recommend ≥1 measurement on each occasion without denying that multiple measurements might be of value. This recommendation is based on the hypothesis that single measurements would be more convenient and result in better compliance.[5,22] In our study, the second measurement produced, on average, 3/1-mm Hg lower BP values than the first measurement and increased the predictive value of systolic BP. However, performing 2 measurements on each measurement occasion doubles the amount of time and labor required, which could result in poorer patient compliance. Compliance to measurements was good in our study, but this was an epidemiological study without a doctor-patient relationship and with self-reported BP readings, which are not necessarily as reliable as BP measurements read from an automatic monitor equipped with a memory.[23] In real-life clinical practice, adherence to measurements may not be as good as

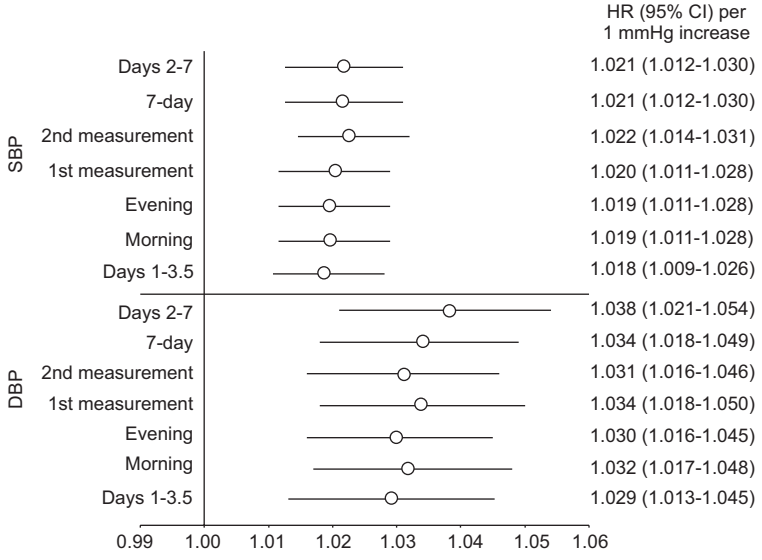

Figure 2. Predictive values of various home blood pressure (BP) measurement indices. Hazard ratio (HR) and 95% CI of days 1.0 to 3.5, morning, evening, first measurement, second measurement, 7-day, and days 2 to 7 home systolic blood pressure (SBP) and diastolic blood pressure (DBP) levels adjusted for the same factors as in Figure 1. Open circles are HR are expressed as an increase in cardiovascular event risk per 1-mm Hg elevation of SBP and DBP. Horizontal lines represent 95% CI.

Table 3. Increases in Goodness of Fit by Progressively Adding BP Indices

	Systolic		Diastolic	
Model	LR χ^2	*P*	LR χ^2	*P*
1				
7-d	0.5	0.50	1.7	0.19
Days 2 to 7	1.4	0.24	3.1	0.08
2				
First measurement	1.2	0.27	1.8	0.18
Second measurement	5.5	0.02	0.1	0.72
3				
Morning	3.2	0.08	2.7	0.10
Evening	0.4	0.54	0.2	0.66
4				
Days 1.0 to 3.5	1.3	0.26	3.2	0.07
First measurement	4.2	0.04	9.3	0.002
5				
Days 1.0 to 3.5	3.5	0.06	0.5	0.46
Second measurement	12.3	<0.001	3.2	0.07

Table shows increases in goodness of fit from adding 1 BP index to a model including another index and vice versa. χ^2 value of 3.8 corresponds with *P* value of 0.05, 6.6 to 0.01, and 10.8 to 0.001. Data were adjusted for sex, age, smoking status, history of cardiovascular events, presence of diabetes mellitus, presence of antihypertensive medication, and presence of hypercholesterolemia. BP indicates blood pressure; LR, likelihood ratio.

observed in our study, as demonstrated previously.[23,24] However, it is also possible that adherence could be even better in the real-life doctor-patient relationship. In any case, we feel that home BP should be measured twice, instead of once, on each occasion because of a lower number of required measurement days, a slightly better predictive ability, and the regression to the mean effect. On the other hand, additional research is still needed on this matter, because our study does not address the significance or the compliance of measuring BP ≥3 times on 1 occasion.

Current European guidelines recommend discarding home BP measurements made on the first day, because higher and more unstable values are usually obtained during the first home BP measurements.[7] This phenomenon has been shown in studies on selected hypertensive populations,[21,25] and it appears to be present also in the population as a whole.[14,16] The plateau level that is reached in BP with an increasing number of home BP measurements, as the patient becomes acquainted with home measurement, could therefore best represent the subjects' "true" BP level. However, results from the Ohasama Study and our study suggest that discarding the first day of measurements could not necessarily be applicable from the view point of prognostic significance.[14] Because of the large overlap in the mean BP for days 1 to 7 and days 2 to 7, the significance of the first day is quite miniscule. Another reason that speaks against discarding the values obtained during the first day of measurement is that they do not show a weaker correlation with target organ damage than the other days of measurement.[19,20] In addition, discardment of the first measurements results in a more complex measurement protocol, and the alerting reaction seen during the first days of the initial measurement week will most likely attenuate during the following week-long measurement sessions. We, therefore, recommend that the values obtained during the first day of measurement should not be discarded.

The differences in morning and evening home BP in the general population are quite small, <2 mm Hg.[16,26,27] This study and a previous study by Asayama et al[15] also demonstrate that morning and evening home BPs seem to provide equally useful information for cardiovascular risk. However, antihypertensive treatment alters the difference between morning and evening BPs, and morning hypertension might be a slightly better predictor of stroke risk among individuals using antihypertensive medication.[15] This subgroup analysis was not performed in our study because of the low number of events among the treated hypertensives (n=63). Trough morning home BP measurements combined with evening measurements can also be used for assessing the duration of antihypertensive drug action in patients.[28,29] In addition, having knowledge of a patient's relatively greater morning-evening BP difference can raise suspicion of underlying alcoholism, sleep apnea, or cardiovascular disease.[30] Home measurements in the morning and in the evening are therefore recommended to obtain a thorough image of the average BP and to evaluate the round-the-clock efficacy of antihypertensive medication.

Perspectives

Current guidelines based on cross-sectional statistical parameters derived from reference populations make equivocal recommendations for the optimal schedule of home BP measurement. Novel prognostic data from this study show that measurement of home BP twice in the morning and evening, preferably for a period of 7 days or for ≥3 days, is recommended for obtaining a thorough image of a patient's true BP level. Unfortunately, the recommended number of home measurements is a double-edged sword. Although a longer period of measurement increases diagnostic accuracy, the probability of lower compliance and errors in a generalized use increases at the same time. Therefore, characterization of those who will or will not be compliant needs more study. The results of our study also need to be validated in large-scale meta-analyses, which would also make subgroup analyses possible, but were not performed in this study because of the relatively small number of events. However, we feel that novel information from this study should be used to prepare a unified international guideline for home BP measurement.

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Disclosures

None.

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