The optimal scheme of self blood pressure measurement as determined from ambulatory blood pressure recordings

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Objective **To determine how many self-measurements of blood pressure (BP) should be taken at home in order to obtain a reliable estimate of a patient's BP.**

Design **Participants performed self blood pressure measurement (SBPM) for 7 days (triplicate morning and evening readings). In all of them, office blood pressure (three consecutive readings) and 24-h ambulatory blood pressure were obtained as well. Average SBPM values, obtained from several combinations of readings, were correlated with the results of ambulatory blood pressure measurement (ABPM). In addition, we assessed whether certain patient characteristics would influence such correlations.**

Setting **Patients were recruited at hospital or general practice.**

Patients **A total of 216 untreated hypertensive patients.**

Results **The average SBPM value calculated from day 3 to day 7, omitting the first measurement of each morning and evening session, gave the best correlation with 24-h ABPM ($r = 0.70$). However, similar results were obtained from a SBPM value averaged from day 3 until 5 without the first measurement of each triplicate session. Overall, younger patients had significantly better correlations than older ones. Women had significantly better correlations with ABPM than men for systolic morning and daytime SBPM, whereas men had significantly better correlations for daytime and evening diastolic SBPM ($P < 0.001$). In addition, all correlations increased with lower systolic office blood pressure measurement (OBPM) values.**

Conclusions **A minimum number of 5 days of measurement is recommended to obtain a reliable estimate of a patient's usual BP. On each day, three consecutive morning and evening measurements should be performed. For calculating the average SBPM, the first 2 days and the first measurement of each triplicate measurements should be discarded. Moreover, patient characteristics may have an impact on the number of necessary self-measurements. However, because adhering to these recommendations will make SBPM a time-consuming procedure, this type of measurement should be performed only when a decision about starting or changing antihypertensive therapy is needed or in the case of special patient groups.** ***J Hypertens*** **24:1541–1548 © 2006 Lippincott Williams & Wilkins.**

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Introduction

Self blood pressure measurement (SBPM) is becoming increasingly popular. Indeed, SBPM has many advantages above office blood pressure measurement (OBPM) such as the elimination of the white-coat effect [1] and a better correlation with both ambulatory blood pressure measurements [2] and target organ damage [3–6]. These considerations have led several authoritative bodies to recommend the use of SBPM for clinical practice [7,8].

Despite the popularity of SBPM, there are no evidence-based guidelines with respect to the number of SBPMs that should be obtained for optimal assessment of a patient's usual blood pressure (BP). Although several studies have addressed this issue [9–13], their protocols varied widely in terms of number of subjects, sort of analysis and methods of BP measurement. Not surprisingly, therefore, these investigations resulted in different outcomes. Recommendations diverged from taking the average of two readings for three consecutive measurement days [10] to more than 14 days of SBPM [12]. This makes it difficult to reach consensus and give recommendations that are based on clinical evidence. Moreover, in these studies patient characteristics (gender, age, etc.) have not sufficiently been taken into account.

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In the present study, we have tried to establish the optimal number of SBPM by comparing SBPM results directly with data obtained with 24-h ambulatory blood pressure measurement (ABPM), which is still considered to be the 'gold standard' in BP measurement. In most studies ABPM appeared to correlate better with target organ damage [14,15] and to be superior when it comes to prediction of cardiovascular risk than conventional BP measurements [14,16–18]. In contrast to earlier studies, we have also investigated the influence of certain patient characteristics on the correlation between SBPM and ABPM.

Methods

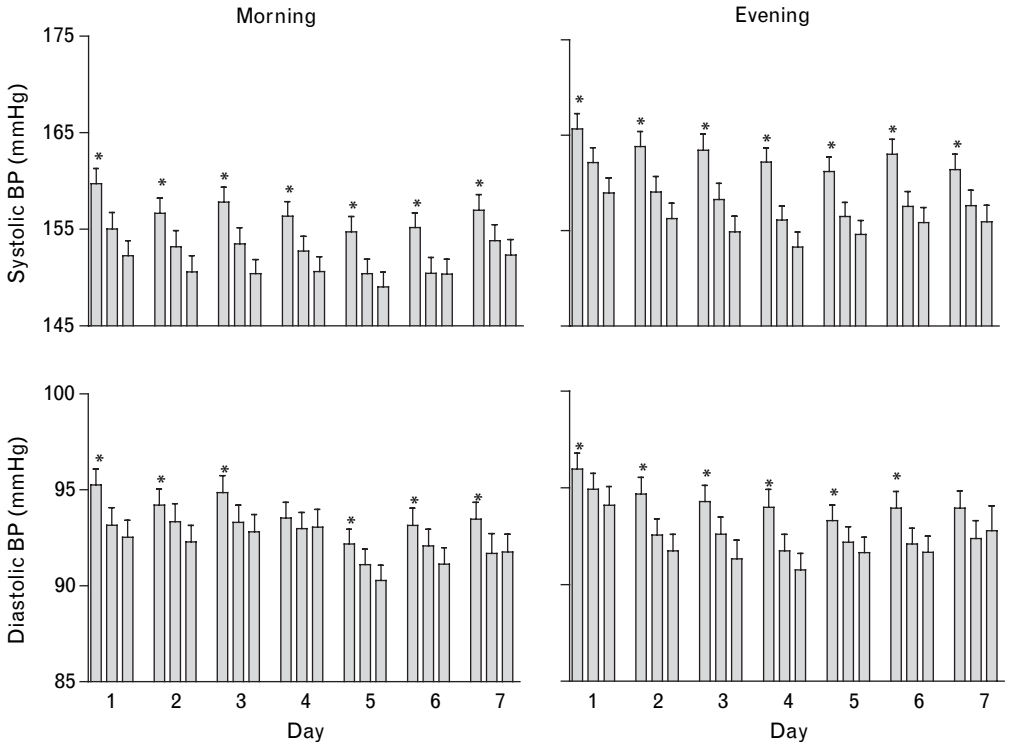
Patients

Patients who participated in this study formed a subpopulation of the HOMERUS-trial, the design of which has been described previously [19]. Altogether, 216 mild to moderate hypertensive patients (118 male, 55%) with a mean age of 55 ± 11 years and a body mass index of 28 ± 4 kg/m^2, who all performed SBPM, were available for analysis. Patients had a mean OBPM of $166 \pm 19/97 \pm 10$ mmHg without antihypertensive treatment. As part of the HOMERUS-protocol, echocardiography and assessment of urinary micro-albumin excretion were performed to estimate the degree of target organ damage. All patients gave their informed consent and the medical ethics committee approved the study protocol.

Blood pressure measurements

Triplicate OBPMs were taken at the hospital or in the general practitioner's office when they were without antihypertensive therapy for a period of at least 4 weeks. SBPM was performed, at the patient's home, six times a day (three measurements in the morning and three in the evening) for a 7-day period prior to the patient's visit to the office. Morning measurements were performed after voiding and before breakfast. Each individual was requested to register his/her self-measurements on a form and, additionally, to print out all measurements. Both OBPM and SBPM were performed at the patient's non-dominant arm, in a sitting position, after 5 min of rest with 1 min between the measurements and using the same fully automated device (Omron HEM-705 CP Omron Corporation, Tokyo, Japan). This device has passed the validation protocol of the British Hypertension Society [20]. Additionally, ABPM was performed with a Spacelabs automatic device (SpaceLabs Medical Inc. Redmond, USA). BP was measured every 15 min between 0700 and 2300 h and every 30 min during nighttime. The average daytime ABPM value was calculated from 0900 to 2100 h on the first day and the average nocturnal ABPM was determined from 0100 to 0600 h,

Fig. 1



Triplicate morning and evening home blood pressure (BP) measurements assessed during a 7-day period in patients without hypertensive treatment. Results are expressed as means ± SEM; *indicates that measurements are significantly higher than subsequent ones ($P < 0.001$).

according to European Society of Hypertension (ESH) recommendations [21]. In all registrations, the initial hour after the device had been hooked up was omitted from analysis.

Statistical analysis

The relationship between SBPM and ABPM was analysed for several combinations of ABPM and SBPM data. Average ABPM and SBPM values obtained from morning, evening and daytime (average of morning and evening data) measurements were compared. Regression analysis was applied to assess the relationship between self-measured blood pressure and ABPM. Results were expressed as the correlation coefficient r. Groups were compared according to the following characteristics: age (three different age groups; < 50, 50–60, > 60 years), gender, level of systolic and diastolic mean OBPM (in quartiles), and for a combination of age (< 50 and ≥ 50 years) and gender.

For all tests, we examined whether the highest correlation was significantly different from the others. This was performed by bootstrap simulation [22]. Statistical calculations were performed using SPSS version 12.0 (SPSS Inc., Chicago, Illinois, USA).

Results

Figure 1 shows that on all 7 days of SBPM, the first measurement of each triplicate was significantly higher than subsequent ones for both morning and evening systolic pressure ($P < 0.001$) and for most diastolic BP measurements. BP measurements on the first day were significantly higher than measurements on subsequent days ($P < 0.05$). Overall, evening self-measurements were significantly higher than morning measurements for systolic ($P < 0.001$) but not for diastolic BP.

Correlations of self blood pressure measurement with ambulatory blood pressure measurement

Initial analyses were performed with either 24-h ABPM or daytime ABPM or nocturnal ABPM as the independent variable. The correlations of SBPM data with those from 24-h, daytime and nocturnal ABPM are illustrated in Table 1. Results indicate that there were no significant differences between morning, day and nocturnal correlations, and that SBPM tends to correlate better, although not significantly so, with 24-h ABPM ($r = 0.70$, for the highest systolic correlation) than with daytime ABPM ($r = 0.65$) or nocturnal ABPM ($r = 0.60$). Consequently, we further used 24-h ABPM only as the comparator. Taking all measurements into consideration, the best correlations were obtained when SBPM was determined during 7 days of measurement, omitting the first 2 days. Bootstrap analysis showed that significant differences from the highest correlation started to occur when fewer than 5 days of SBPM were available. Overall, correlations tended to improve for all values when the results of the first 2 days of measurement were omitted (with the r-value rising by 0.01 to 0.03) and/or when the first measurement of each triplicate session was discarded (r-value improving by 0.01 to 0.04), but none of these changes was statistically significant.

Effect of patient characteristics

Gender

Figure 2 illustrates that women who performed SBPM had a significantly better correlation to 24-h ABPM of both daytime and morning systolic SBPM ($P < 0.05$) than men, whereas men had a better correlation for daytime and evening diastolic BP ($P < 0.001$). Although in men the evening correlation was significantly better than the morning correlation for systolic BP ($P < 0.05$), both morning and evening correlations were significantly lower than daytime correlations ($P < 0.05$). Women, on the other hand, had significantly better morning than evening correlations for both systolic ($P < 0.001$) and diastolic BP ($P < 0.05$), and this morning correlation did not differ from the daytime SBPM correlation. Bootstrap analysis revealed that in men no significant intra-group differences from the highest correlation occurred until the measurement period lasted only 2 days, whereas women had to measure for at least 4 days.

Age

After dividing the study population into three groups according to age (Fig. 3), the highest correlations were obtained in patients younger than 50 years of age. In particular, correlations for systolic SBPM were significantly higher in this group than in patients who were 50–60 years old ($P < 0.05$). However, they were not when compared to patients above 60 years. Diastolic SBPM correlated significantly better with ABPM in patients under 50 years as compared to both older age groups ($P < 0.001$). Intra-group analysis showed that in all three age groups the highest correlation value did not differ significantly from other correlations.

Office blood pressure

Figure 4 illustrates the study population broken down into four groups according to their average systolic OBPM. Systolic BP correlations of the two groups with the lowest systolic OBPM values (122–153 and 153–165 mmHg) were significantly higher than the correlations of the two groups with the highest values (165–179 mmHg, $P < 0.05$ and 180–221 mmHg, $P < 0.001$). These differences were not apparent with respect to diastolic BP.

Correlations of self blood pressure measurement with target organ damage

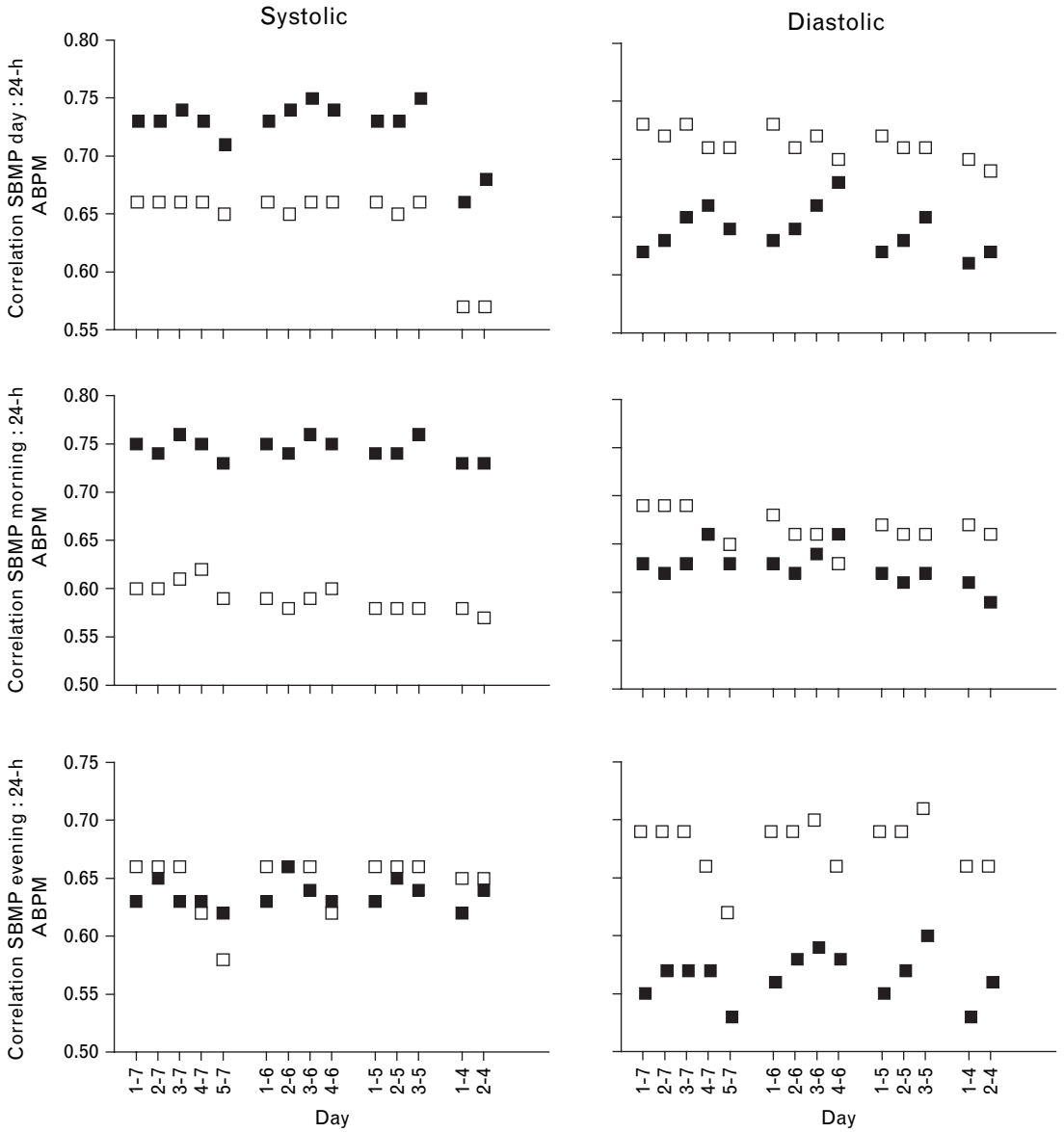
Correlations of SBPM with left ventricular mass index (LVMI) were low (r ranged from 0.10 to 0.25) for both systolic and diastolic SBPM values and did not differ among days of measurement. The same held true for urinary micro-albumin concentration. Neither 24-h ABPM

Table 1 Correlation coefficients (*r*) of self blood pressure measurement (SBPM) values with 24-h, daytime or nocturnal ambulatory blood pressure measurements (ABPM)

	24-h ABPM						Daytime ABPM						Nocturnal ABPM					
	Day		Morning		Evening		Day		Morning		Evening		Day		Morning		Evening	
	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic	Systolic	Diastolic
Day 1–7	0.70	0.69	0.69	0.69	0.64	0.62	0.65	0.66	0.63	0.65	0.58	0.60	0.60	0.59	0.57	0.59	0.56	0.52
Day 2–7	0.70	0.69	0.68	0.68	0.65	0.62	0.65	0.66	0.63	0.64	0.60	0.61	0.60	0.59	0.58	0.59	0.55	0.51
Day 3–7	0.71	0.69	0.69	0.68	0.64	0.62	0.66	0.67	0.65	0.65	0.59	0.62	0.60	0.59	0.59	0.58	0.55	0.52
Day 4–7	0.71	0.70	0.69	0.68	0.62	0.60	0.66	0.67	0.65	0.64	0.58	0.60	0.61	0.59	0.59	0.59	0.54	0.50
Day 5–7	0.69	0.68	0.68	0.66	0.60	0.57	0.64	0.66	0.62	0.62	0.56	0.56	0.60	0.58	0.59	0.58	0.53	0.48
Day 1–6	0.69	0.69	0.67	0.68	0.64	0.62	0.64	0.66	0.62	0.64	0.58	0.61	0.60	0.58	0.56	0.58	0.56	0.52
Day 2–6	0.69	0.69	0.67	0.67	0.65	0.62	0.65	0.66	0.62	0.63	0.60	0.62	0.59	0.58	0.56	0.58	0.55	0.51
Day 3–6	0.71	0.69	0.68	0.67	0.64	0.63	0.66	0.67	0.63	0.64	0.59	0.62	0.60	0.58	0.57	0.57	0.55	0.52
Day 4–6	0.70	0.69	0.68	0.67	0.62	0.61	0.66	0.67	0.64	0.63	0.58	0.61	0.60	0.58	0.57	0.57	0.54	0.50
Day 1–5	0.69	0.69	0.67	0.67	0.64	0.62	0.63	0.66	0.62	0.63	0.58	0.61	0.59	0.58	0.56	0.58	0.55	0.52
Day 2–5	0.69	0.69	0.66	0.66	0.65	0.62	0.64	0.66	0.61	0.62	0.60	0.62	0.59	0.58	0.56	0.57	0.54	0.52
Day 3–5	0.71	0.69	0.68	0.66	0.65	0.64	0.66	0.66	0.63	0.63	0.60	0.63	0.59	0.58	0.57	0.56	0.55	0.53
Day 1–4	0.68	0.66	0.66	0.66	0.62	0.60	0.62	**0.63**	0.61	0.62	0.57	0.58	0.58	0.56	0.55	0.57	0.54	0.50
Day 2–4	0.69	**0.66**	0.66	0.65	0.63	0.60	0.62	0.62	**0.61**	0.61	0.59	0.58	0.57	0.55	0.55	0.56	0.53	0.50
Day 1–3	**0.66**	0.66	**0.63**	0.66	0.61	0.58	0.60	0.63	**0.57**	0.62	0.56	0.57	0.55	0.56	0.53	0.56	0.52	0.48
Day 2–3	0.66	**0.64**	**0.62**	0.62	0.61	0.57	**0.60**	**0.61**	**0.56**	**0.58**	0.57	0.55	0.55	0.54	0.54	0.53	0.49	0.46
Day 3	**0.66**	**0.62**	**0.62**	0.59	0.59	0.56	**0.61**	**0.60**	**0.57**	**0.57**	0.55	**0.54**	0.54	0.51	0.51	**0.48**	0.49	**0.45**
Day 1–2	**0.62**	**0.63**	**0.60**	0.62	0.57	**0.54**	**0.57**	**0.61**	**0.54**	**0.58**	**0.52**	**0.53**	**0.53**	**0.53**	**0.51**	**0.54**	**0.50**	**0.45**
Day 2	**0.61**	**0.57**	**0.56**	**0.54**	0.57	**0.49**	**0.55**	**0.55**	**0.49**	**0.49**	0.53	**0.49**	**0.52**	**0.50**	**0.51**	**0.49**	**0.47**	**0.42**
Day 1	**0.57**	**0.61**	**0.57**	0.65	**0.53**	**0.48**	**0.53**	**0.59**	**0.53**	**0.62**	**0.47**	**0.47**	**0.47**	**0.49**	**0.47**	**0.56**	**0.48**	**0.38**

Average SBPM values were determined from triplicate morning and/or evening measurements. The first measurement from each triplicate session was discarded. Day 1–7 indicates the average SBPM value calculated from day 1 until day 7; Day 2–7, the average SBPM value calculated from the second until the seventh day, and so on. Numbers in bold indicate that compared to day 3–7 a significant difference ($P < 0.05$) was found with the bootstrap analysis.

Fig. 2



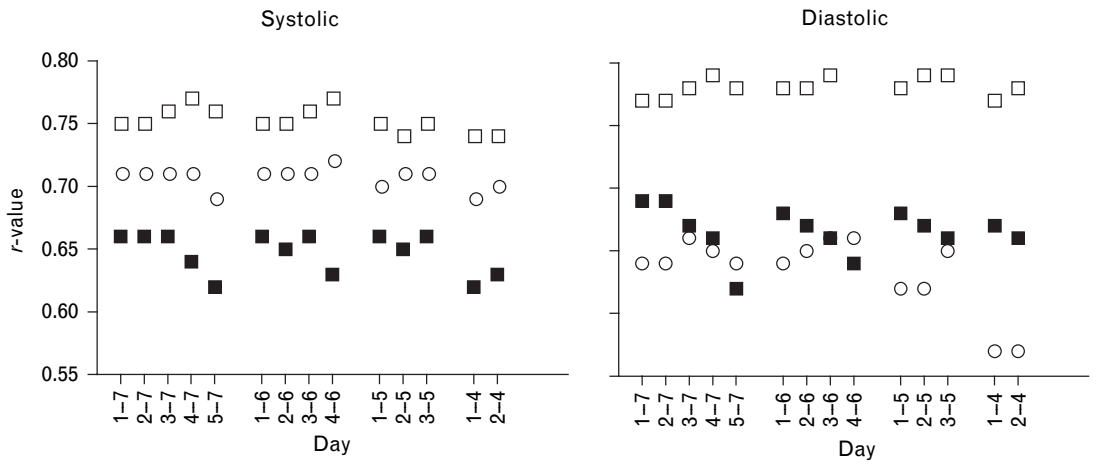
Correlation coefficients (*r*-value) for the relationship between daytime, morning and evening self blood pressure measurements (SBPM) and 24-h ambulatory blood pressure measurements (ABPM) in male (□, $n = 113$) and female (■, $n = 94$) patients for both systolic and diastolic blood pressure.

or OBPM showed any significant relationship with left ventricular mass index or with urinary micro-albumin excretion.

Discussion

The present study shows that the best correlation of SBPM with 24-h ABPM was obtained when SBPM was performed during a 7-day period and the data of the first 2 days and the first measurement of each triplicate session were discarded. However, similar results were obtained from a minimum number of 5 days of measurement without the results of the first 2 days and the first measurement of each triplicate session. Correlations consequently improved, though not always significantly, when the first 2 days of measurement, and/or the first measurement of each triplicate session, were discarded. The highest correlations were obtained when SBPM was compared with 24-h ABPM, but these correlations did not deviate significantly from correlations of SBPM with either daytime or nocturnal ABPM values. When analysed according to gender, data suggest that in men it is not sufficient to perform morning measurements only, as both morning and evening correlations differ significantly from daytime correlations. Moreover,

Fig. 3

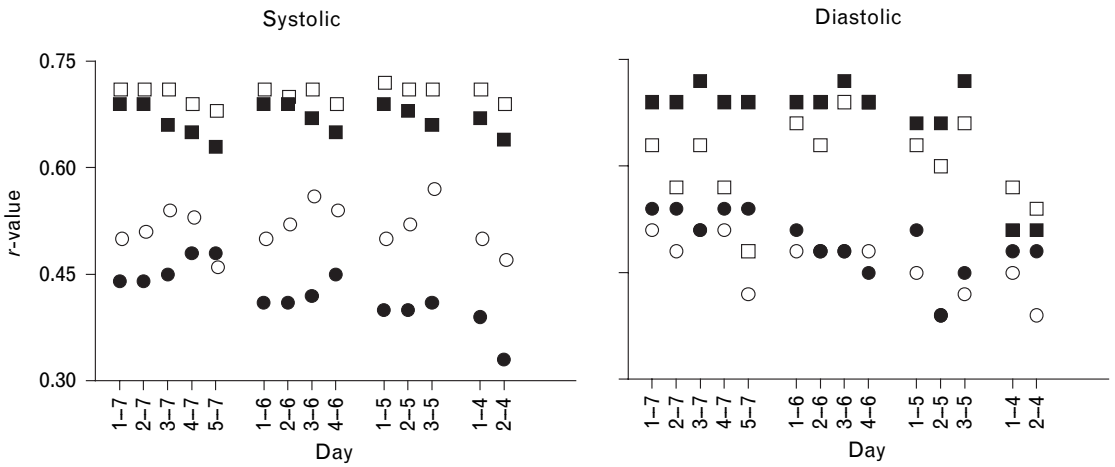


Correlation coefficient (*r*-value) for the relationship between daytime self blood pressure measurements (SBPM) and 24-h ambulatory blood pressure measurements (ABPM) for three different age groups. Age < 50 years (□, $n = 57$); 50–60 years (■, $n = 113$) and older than 60 years (○, $n = 74$), for systolic and diastolic blood pressure.

patients with lower systolic OBPM had significantly higher correlations than those with higher systolic OBPM, and younger patients (< 50 years) had correlations which were significantly higher than those in the elderly. This suggests that patient characteristics should be taken into account when it comes to recommendations about SBPM. Apparently, variables such as age, gender and systolic OBPM have a major impact on the correlation between SBPM and ABPM. There was a low correlation of SBPM with target organ damage, which did not change with days and number of measurements.

Our study should be interpreted in the context of its limitations. Discarding the first 2 days of measurement and the first measurement of each triplicate session improved the correlations, but not significantly so. This may, therefore, indicate that it is not absolutely necessary to recommend omitting these measurements. However, we cannot exclude that, in a larger group of subjects, differences would become statistically significant. Moreover, by omitting these first readings one obtains a more stable estimate of a patient's blood pressure.

Fig. 4



Correlation coefficient (*r*-value) for the relationship between daytime self blood pressure measurements (SBPM) and 24-h ambulatory blood pressure measurements (ABPM) for four different groups, separated according to their average systolic blood pressure value as measured in the physician's office. The systolic blood pressure values ranged from 122–153 mmHg (□, $n = 52$), 153–165 mmHg (■, $n = 52$), 165–179 mmHg (○, $n = 52$) and 180–221 mmHg (●, $n = 51$).

Another limitation is that one should preferably base the number of necessary SBPMs on prognostic studies in which the number of SBPMs can be related to cardiovascular events. Such a study has been performed by Ohkubo *et al.* [12]. In that study, SBPM consisted of approximately 14 measurements during a period of 2 weeks. The data were related to the incidence of stroke during 10.6 years of follow-up. However, over such a long period of time, substantial changes in BP may have occurred. In addition, the population had a high mean age (61 years) and largely contained women (67%). Therefore, these results should be interpreted with caution. Alternatively, one may suggest that recommendations concerning SBPM should be based on its relationship with organ damage. However, a correlation with BP and organ damage may not be readily apparent, as organ damage develops over a long period of time and it depends on when BP is taken whether a correlation will be found or not. In the present study, we failed to find correlations with either LVMI or micro-albuminuria. However, at the time the degree of organ damage was determined, patients had just finished a placebo run-in period of 4 weeks, during which previous antihypertensive treatment had been stopped. It is not surprising, therefore, that we could not find a relationship of SBPM data with target organ damage since the latter better reflected blood pressure status before enrolment into the study. Thus, due to the specific design of this study we were unable to correlate SBPM data with the degree of target organ damage. This paper should, therefore, be considered merely as an contribution as to how the most reliable BP value at home should be obtained.

In recent years, several studies have addressed the optimal number of measurements in SBPM, but these differed from our study in some essential aspects. A few based their recommendations on single readings [10,12] even though it is generally accepted to take at least two consecutive measurements [21]. Celis *et al.* [9] compared their SBPM results to OBPM data, while ABPM is a more reliable method of BP measurement. Indeed, an important reason to implement SBPM in healthcare is that it is supposed to better reflect a patient's usual BP than OBPM, and thus comparing SBPM to OBPM in order to give recommendations is not appropriate. The study of Stergiou *et al.* [13] resembles ours most, but it differs in various aspects as well. Like us, these investigators correlated SBPM with ABPM and found that measurements on the first day were higher than those on subsequent days and, therefore, they recommended omitting these measurements. However, a difference from our study is that they instructed their patients to perform only two measurements. Although the ESH recommendations state that at least two measurements should be obtained, they also emphasize that repeated measurements should be performed if there is uncertainty or distraction [21]. Moreover, our data show clearly that the first measurement is always significantly higher than subsequent ones. This implies that the average of a second and a third reading are more likely to yield a stable BP value than when the first two measurements are averaged.

It may seem that our recommendation for 5 days of measurement may create too large a burden for patients. However, this measurement procedure only has to be performed when a decision about starting or changing antihypertensive therapy is needed, or when it is essential to know a patient's BP exactly, as, for example, in some elderly subjects or in diabetics. Otherwise, a minimum measurement of 1 week per quarter may suffice [23]. Additionally, discarding the first 2 days of measurement and the first measurement of each session may seem a waste of time and measurements for patients and practitioners. However, due to an increased cuff response, values are deviating from subsequent values and therefore may disturb reproducibility of BP data. As already shown by other studies the effect of adaptation highly influences readings and should, therefore, not be underestimated [13]. Since the cuff response seems to diminish when patients measure their BP more frequently, discarding the first measurements may no longer be necessary after several SBPM sessions have been performed and the patient is familiar with the procedure.

Discarding measurements of the first days, as well as discarding first measurements of each triplicate session, leads to lower BP values. For that reason, one may have to consider to establish new (lower) reference values, which should be determined according to the risk of developing cardiovascular disease in the future. Although this is complicated and very time-consuming, we may have to pursue this as it is the only way to determine precisely the predictive value of SBPM.

How should our results be interpreted in the light of existing recommendations concerning SBPM? Although the guidelines of the ESH clearly state that at the time no study had analysed the optimal timing and frequency of measurements [21], it was proposed to follow the recommendations of the German Hypertension League [23]. Although the number of measurements in our study was slightly greater, by and large our data confirm the validity of those recommendations. Therefore, we now provide the evidence which was previously lacking. Nevertheless, we add new information concerning the impact of gender, age and the level of office blood pressure. This information should, therefore, be considered in future adaptations of the guidelines.

In conclusion, the minimum number of SBPM necessary to obtain a BP value that correlates best with ABPM is 5

days of measurement. Each day, three consecutive morning and evening measurements should be performed, and the first 2 days and the first measurement of each triplicate session may have to be discarded. For women, on the other hand, it may be sufficient to perform morning measurements only.

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