The optimal schedule for self-monitoring of blood pressure by patients at home
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The optimal schedule for home blood pressure monitoring should represent the usual level of home blood pressure, give a reproducible value, and have prognostic ability. Therefore, outcome studies, as well as short-term trials assessing the reproducibility of home blood pressure, its stability over time and its relationship with ambulatory blood pressure should be taken into account. A review of this evidence suggests that the optimal schedule should be based on 12–14 measurements, and even more measurements up to 25 are desirable. Morning and evening measurements should be obtained, with at least duplicate measurements per occasion. Measurements on the initial day should preferably be discarded. J Hypertens 25:1992–1997 © 2007 Lippincott Williams & Wilkins.

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Introduction
Self-monitoring of blood pressure by patients at home is increasingly being used and has been endorsed by hypertension societies worldwide [1,2]. Home blood pressure monitoring allows the detection of the white-coat and masked hypertension phenomena, and appears to be the most appropriate method for the long-term follow-up of treated hypertension [3]. In addition, home blood pressure has been shown to be one of the few measures that can improve patients’ compliance and hypertension control rates [4,5].

For the optimal implementation of home blood pressure monitoring, clear and straightforward recommendations need to be provided on how this method should be applied in everyday practice. Patients as well as doctors need to be instructed on how often, at what time of the day, and with how many measurements per occasion home blood pressure should be obtained in order to take full advantage of the method.

To decide on the optimal home blood pressure monitoring schedule, it should be taken into account that the ability of a given procedure for blood pressure measurement to predict cardiovascular risk is of paramount importance. This feature is definitely a major prerequisite in order to support the use of any blood pressure measurement method in clinical practice. However, because the physician each time assesses only one individual, and therefore the stability and the reproducibility of the measurement are also crucial. For example, although in the Ohasama [6] and the PAMELA [7] outcome studies only two home blood pressure readings have been shown to provide strong prognostic value, in the individual patient in practice it would not be sensible to recommend decision making on the basis of only two home blood pressure readings. Thus, the ability of the recommended schedule to provide a reliable and reproducible assessment of the ‘usual’ home blood pressure of each individual is thus also crucial.

Which schedule best predicts the risk of cardiovascular events?
The Ohasama was the first outcome study to assess the usefulness of home blood pressure monitoring [6]. That study provided a unique database of home blood pressure measurements that allowed extensive analyses addressing fundamental issues, such as the prognostic significance of home blood pressure, the normal range of home blood pressure values, and the optimal schedule for their measurement, on the basis of outcome data. Outcome data from four other studies using home blood pressure monitoring have recently confirmed the findings of the Ohasama study [6] regarding the prognostic value of this method [7–10]. However, all those studies are more or less imperfect, and differ significantly from each other in several respects, and are therefore difficult to combine for interpretation. The Ohasama study [6] in 1789 subjects from a general population in Japan obtained only single morning home blood pressure measurements but for 28 days (total of 28 self-measurements). The SHEAF study in France [8] was the largest study that included 4938 treated elderly hypertensive individuals and used triplicate morning and evening measurements for 4 days (total of 24 self-measurements). The PAMELA study [7] in 2051 subjects from a general population in northern Italy...
obtained only a single morning and evening home blood pressure measurement in one day (total of two self-measurements). The Didima study in Greece [9] is a smaller general population study in 665 subjects that obtained duplicate morning and evening measurement for 3 days (total of 12 self-measurements). Finally, the Flanders study [10] is the smallest, performed in 391 patients of a primary care practice in Belgium that obtained triplicate home blood pressure measurements taken by a physician at home on a single occasion (total of three measurements).

It is interesting to note that, despite using such a wide variety of home blood pressure monitoring schedules, studies consistently showed strong prognostic value of home blood pressure measurements [6–10]. It appears that even a few home blood pressure readings are able to predict the risk of cardiovascular events in groups of subjects, as shown in the PAMELA study (a total of two measurements per patient) [7], the Ohasama study (the first two measurements) [6], the Didima study (the first two measurements) [9] and the Flanders study (total of three measurements) [10]. However, the Ohasama study [11] showed a progressive increase in the prognostic value of home blood pressure in relation to stroke, without any threshold, by increasing the number of measurements up to 14, with a modest additional benefit by averaging all 25 measurements. The prognostic superiority of home blood pressure compared with the conventional office measurements thus appears to be a result of the different site (individual’s own environment) but also the larger number of measurements. This is not surprising, given the intrinsic physiological variability that characterizes blood pressure [12,13]. This property makes isolated spot blood pressure measurements less likely to reflect adequately the actual load exerted by blood pressure on the cardiovascular system than the average of repeated blood pressure measurements [14].

**Conclusion 1**

Even a few home blood pressure measurements have strong prognostic value in a large group of subjects as those of the outcome studies. The prognostic ability of home blood pressure, however, seems to be improved by averaging an increasing number of readings up to 14, with a modest additional benefit by averaging 25 readings.

**How to define a reliable and reproducible schedule?**

Several studies have investigated the optimal home blood pressure monitoring schedule on the basis of the reproducibility of home blood pressure, its stability over time and its relationship with ambulatory blood pressure values. In defining the optimal home blood pressure monitoring schedule on the basis of these data, there are four key questions that should be addressed: (i) how many home blood pressure measurements should be averaged; (ii) how many times per day should measurements be taken; (iii) how many measurements should be taken per occasion; and (iv) whether some of the measurements should be discarded.

**How many measurements should be averaged?**

As is the case with ambulatory blood pressure [15–18], the reproducibility of home blood pressure is clearly dependent on the number of measurements that are averaged [19]. Chatellier et al. [19] showed that the maximal reproducibility of home blood pressure (reduction in the standard deviation of differences between the average values of two home blood pressure sessions) is obtained when 30 readings are averaged (three measurements per day for 10 consecutive days). Eighty per cent of this maximal reduction is, however, obtained by averaging 15 measurements on the first 5 days. On the other hand, Imai et al. [20], although confirming that the reproducibility of home blood pressure is at least partly dependent on the number of measurements, provided evidence that no further improvement is obtained by increasing the number of home blood pressure readings above five. This conclusion is in agreement with the results of the SMART study [21], which also showed that, after only six home blood pressure measurements, a small decrease in the standard deviation of the mean difference in average home blood pressure values between two sessions is achieved.

A study by Stergiou et al. [22] in 189 hypertensive subjects assessed the reliability of home blood pressure on the basis of the stabilization of mean home blood pressure over time, its variability (standard deviation of average value within a session) and its relationship with the ambulatory blood pressure values. In addition, the reproducibility of home blood pressure was quantified using test–retest correlations and the standard deviation of mean differences between average home blood pressure values of different days. This study showed that at least 12 measurements taken on 3 days are needed for the reproducibility of home blood pressure to be superior to that of office measurements [22]. These findings were confirmed by another study by the same group that assessed the reproducibility of home blood pressure in 133 untreated hypertensive individuals [23]. A study on stress management training in 43 hypertensive patients also used test–retest correlations and the standard deviation of differences between repeated home blood pressure measurements and also other more complex statistics, and showed that the average of single evening readings taken over three consecutive days provides a reliable estimate of home blood pressure levels [24]. A study by Celis et al. [25] in 74 elderly subjects also showed that 3 days of sitting home blood pressure measurements may suffice to obtain steady values. Finally, a study by Mengden et al. [26] suggested that a 7-day schedule with duplicate morning and evening
measurements is appropriate when using home blood pressure monitoring for clinical pharmacology trials.

Brook [27] reviewed 12 home blood pressure studies that used considerably variable schedules, and investigated the effect of the different schedules on the accuracy of the resulting home blood pressure averages. The accuracy of home blood pressure average values, as determined by their agreement with average ambulatory blood pressure values, was not related to any of the home blood pressure schedule parameters considered, including the total number of measurements, the number of measurements per session, the number of sessions per day, and the total duration of monitoring. The author also concluded that, on a statistical basis, most of the benefits derived from home blood pressure monitoring can be achieved by obtaining only a few home blood pressure measurements through a very simple monitoring schedule [27] (i.e. by considering as few as two home blood pressure readings obtained on a single day).

**Conclusion 2**
The number of home blood pressure readings averaged is probably more important than the monitoring schedule, and 12 measurements obtained in 3 days appear to be the minimum required. Given that home blood pressure is easily accepted by patients and has a relatively low cost, it appears reasonable to recommend an average of more readings than the statistically minimum reliable schedule.

**How many times per day should measurements be taken?**
One of the major limitations of conventional office measurements is the fact that this method gives only a snapshot of blood pressure at a certain point in time, whereas ambulatory monitoring provides more detailed information on the diurnal blood pressure profile. Although home blood pressure monitoring cannot provide the large amount of data obtained by ambulatory monitoring, home blood pressure can be easily measured by patients two to three times per day, as shown in several large trials [9,21,28,29], even in the elderly [8] and in children and adolescents [30]. In treated hypertension, trough morning home blood pressure measurements combined with evening measurements (morning: evening home blood pressure ratio) might be a useful tool to assess the duration of antihypertensive drug action in individual patients [31,32]. These data, together with the known differences between morning and evening home blood pressure measurements [19,33], suggest that morning home blood pressure measurements probably give an incomplete picture of the blood pressure at home.

**Conclusion 3**
To obtain a more complete picture of home blood pressure, it seems appropriate to recommend measurements to be taken at least twice a day, in the morning (at trough if treated) and again in the evening. This schedule has the advantage that it is easily applicable to most of the hypertensive patients, because it does not interfere with the routine activities even of busy workdays.

**How many measurements should be taken per occasion?**
The variability which characterizes blood pressure offers a theoretical basis for the need for repeated measurements, wherever they are taken. Blood pressure in the office is known to decline in repeated measurements during the same visit even after multiple visits [34]. Therefore, it is recommended that at least two measurements should be taken on each visit. The behaviour of home blood pressure appears to be similar to that in the office, given that studies have shown the first home blood pressure reading to be consistently higher than a second one taken 1 min later, in the morning and the evening, even after repeated monitoring sessions [22,29].

Few of the studies of home blood pressure monitoring have used only single home blood pressure measurements per occasion [6,7], whereas the vast majority have obtained duplicate or triplicate measurements per occasion [8,9,21,22,28–30,35]. In the Didima study [9] the prognostic ability of the first home blood pressure measurement of each morning and evening session of 3 days was compared with that of the average of two measurements of each session taken 1 min apart. This analysis showed a trend for higher prognostic ability of the average of the two measurements compared with the first one, which was consistent across all the morning and the evening sessions of the three monitoring days (unpublished data).

**Conclusion 4**
As it is usually recommended for office blood pressure measurements, in order to take full advantage of the home blood pressure measurement method, it seems appropriate to obtain at least two measurements on each occasion. This approach appears to be easily accepted by patients at no extra cost, and is expected to provide more stable and valid home blood pressure values.

**Should some of the measurements be discarded?**
The first visit in the office is known to provide higher blood pressure values that can often lead to the overdiagnosis of hypertension [34–36]. As is the case with office blood pressure measurement, higher and unstable values are usually obtained on the first home blood pressure monitoring day [21–23]. Therefore, several investigators have regarded the first home blood pressure monitoring day as a training day, and have preferred to discard the corresponding measurements [19,21–23,29,33]. A study by Stergiou et al. [22] in 189 hypertensive subjects showed that the average home blood pressure measurement of the first day provided higher and more unstable values.
(higher standard deviation) than the values obtained over the following days, whereas no difference was observed among days 2–6 [22]. When measurements of the initial day were excluded, the average home blood pressure value of the whole monitoring period was significantly reduced and the correlation of home blood pressure with ambulatory blood pressure was improved [22]. These findings were confirmed by another study by the same group in 133 untreated hypertensive individuals in which the reproducibility of home blood pressure was improved by discarding the first monitoring day [23]. Again, in a study by Celis et al. [25] in 74 elderly subjects, the home blood pressure values of the first day tended to be higher and had the highest standard deviation.

This suggestion that home blood pressure readings on the first day should better be discarded is further supported by a crossover study comparing the effects of two antihypertensive drugs on home blood pressure using repeated home blood pressure monitoring sessions [37]. Average home blood pressure of the initial day was unable to detect any difference in the drug effects on diastolic home blood pressure, whereas a significant difference was detected when average home blood pressure on the second day was used [37]. This drawback of the first day of home blood pressure monitoring was thus consistently present on the first day of any of three home blood pressure monitoring sessions that were repeated at 5-week intervals during the study [37]. Verberk et al. [29] studied 216 untreated hypertensive individuals who monitored their home blood pressure for 7 days (triplicate morning evening measurements), and showed that the strongest associations of average home blood pressure with ambulatory blood pressure were obtained after excluding the measurements of the first 2 days. In the Ohasama study [11], the first and the second home blood pressure days (with single morning readings obtained per day) gave higher (by 2–3/1–1.5 mmHg systolic/diastolic) and more variable home blood pressure values (higher standard deviation of average home blood pressure by 2–3.5/1.5–2.5 mmHg) compared with the average home blood pressure of all readings. Again in the Didima study [9], the home blood pressure of the first day (with duplicate morning and evening measurements per day) was 125.6 ± 21.0/74.1 ± 9.9 mmHg (systolic/diastolic) compared with 123.9 ± 19.9/73.5 ± 9.2 mmHg for the average of days 2–3 (unpublished data). Although these data suggest that the first home blood pressure measurements should be discarded when computing averages, this does not necessarily mean that initial measurements cannot provide prognostic information. Infact, information on blood pressure reactivity to external stimulation, typically exemplified by the quantification of the white-coat effect, may contribute to risk prediction, as shown in several studies including the PAMELA [7], the Ohasama [6] and the DIDIMA studies [9].

Conclusion 5
As is the case with blood pressure measurements of the first office visit, home blood pressure measurements of the first day might give higher and unstable measurements. Therefore, as we tend to ignore measurements of the first office visit and prefer to base decisions on a second one that usually gives lower values, home blood pressure measurements on the first day should better be discarded in order to obtain more reliable and reproducible average values of an individual patient.

Guidelines on self-monitoring of home blood pressure
Although both the European Society of Hypertension [1] and the seventh report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure [2] have endorsed the use of home blood pressure monitoring in clinical practice, neither of these guidelines gave detailed recommendations on how often home blood pressure should be monitored. In 2003, the European Society of Hypertension Working Group on Blood Pressure Monitoring [3] and the Japanese Society of Hypertension [38] provided detailed recommendations on the optimal home blood pressure monitoring schedule.

The Japanese Society of Hypertension guidelines [38] have inevitably been greatly influenced by the Ohasama study [6,11], in which home blood pressure was measured only once in the morning. These guidelines acknowledge the need for obtaining morning and evening measurements, and also the usefulness of obtaining more than one measurement per occasion. It is, however, recommended that only the first measurement on each occasion should be used in calculating average home blood pressure [38]. However, most of the studies included in the International Database of Self-recorded Blood Pressures that proposed thresholds for home blood pressure to be used for decision making, have obtained two to three measurements per occasion [39]. In the Japanese Society of Hypertension guidelines [38] it was speculated that the requirement of two or more instead of single home blood pressure measurements per occasion would reduce patients’ compliance. Data on patients’ preference and compliance are, however, lacking and it may well be that patients prefer duplicate measurements twice a day for 7 days rather than single measurements every day for 4 weeks (both schedules provide 28 measurements). Several studies have shown good patient performance in taking two to three home blood pressure readings per occasion two to three times a day for a few days [8,9,21,28–30]. Interestingly, the Japanese Society of Hypertension [38] did not propose any specific duration of home blood pressure monitoring, but recommended morning and evening measurements for a lifelong period in hypertensive subjects.
The European Society of Hypertension Working Group on Blood Pressure Monitoring [3] recommended home blood pressure monitoring in the morning and the evening for 7 workdays, always with duplicate measurements per occasion. A total of 28 measurements are thus obtained, which is the same sample as in the Ohasama study [6]. According to these guidelines, home blood pressures of the first day should be discarded. As mentioned above, the exclusion of the first day clearly affects the stability and reproducibility of average home blood pressure if two to three measurements are taken in the morning and the evening for a few days [22,23,25,29,37]. However, it is not expected to affect average home blood pressure if single morning measurements are obtained for 28 days, as in the Ohasama study [6]. The European Society of Hypertension Working Group on Blood Pressure Monitoring stated that duplicate home blood pressure measurements taken once per week appear to be appropriate for the long-term self-monitoring of blood pressure in controlled hypertensive individuals. This recommendation was confirmed in the 2007 European Society of Hypertension Working Group on Blood Pressure Monitoring Consensus on Self-home Blood Pressure Monitoring (consensus document under preparation).

In 2005, a Subcommittee of the American Heart Association Council on High Blood Pressure Research [40] provided brief guidelines for home blood pressure monitoring and recommended readings to be taken in the early morning and the evening, with triplicate measurements per occasion, and mentioned that the first one is typically the highest and that the average should be used [40]. No recommendation was given on the duration of monitoring or whether readings of the first day should be discarded.

**Conclusion**

The optimal home blood pressure schedule to be used for decision making in individual patients in clinical practice should: (i) represent the usual level of blood pressure at home; (ii) give a reproducible home blood pressure value; and (iii) have prognostic ability [39,41]. The evidence discussed in this paper suggests that the optimal home blood pressure monitoring schedule should be based on at least 12–14 measurements, and that even more measurements up to 25 are desirable. Morning and evening home blood pressure measurements should be obtained, with at least duplicate measurements on each occasion. Home blood pressure measurements of the initial day provide higher and unstable values, and should better be discarded when computing averages.

Taking into account these requirements, it appears that the proposal of the European Society of Hypertension Working Group on Blood Pressure Monitoring for home blood pressure monitoring is still valid [3]. This monitoring schedule (at least duplicate home blood pressure measurements taken at least twice a day for 7 workdays and discard the first day) has been shown to be practical and well accepted by patients in several trials, and appears to provide a valid assessment of the average level of blood pressure of an individual at home in a certain period of time. It is advisable for each patient to monitor his/her home blood pressure using this 7-day schedule in the last days before each visit to the doctor’s office. This out-of-office profile of blood pressure is aimed at complementing conventional measurements taken by the doctor in the office, in order to make a more accurate diagnosis of hypertension and more precise assessment of blood pressure control in many patients. Future studies assessing the value of different home blood pressure monitoring schedules in predicting cerebrovascular and coronary artery disease in western populations as those obtained for stroke risk in Japan are needed to establish a more prominent role of home blood pressure in decision making in hypertension [11].

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**References**