Ambulatory Blood Pressure Recordings
Reproducibility and Unpredictability

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SUMMARY The accuracy of blood pressure readings taken by the portable semiautomatic blood pressure recorder Remler M 2000 was investigated in 101 unselected, untreated volunteers. On the average, pressures recorded during usual daily activities were lower by approximately 10 mm Hg than pressures measured in the office. However, individual ambulatory pressures could not be predicted from office readings, and the difference varied among the volunteers from +14 to -43 mm Hg. The reproducibility of office and ambulatory pressures was investigated in 84 subjects. There was a highly significant correlation between pressure levels determined at a 3- to 4-month interval with both the conventional auscultatory method in the office and the Remler ambulatory recorder. These data demonstrate that the Remler M 2000 ambulatory blood pressure recorder, when used properly, provides reproducible blood pressure profiles during customary daily activities. The ambulatory blood pressure recorder seems particularly useful for a baseline evaluation of the usual daily blood pressure, which in the individual subject differs in a highly unpredictable manner from the blood pressure measured at the physician's office. (Hypertension 6: 110-114, 1984)

KEY WORDS • blood pressure measurement • ambulatory blood pressure • Remler ambulatory recorder • physician effect on patients • sphygmomanometer • stress

CONTINUOUS ambulatory monitoring of the intraarterial blood pressure has proven to be very useful in evaluating blood pressure profiles and variability in normotensive and hypertensive subjects. Unfortunately, this technique cannot be used for a purpose other than research since the placement of an intraarterial catheter presents a certain risk. At the present time, portable blood pressure recorders are available that make it possible to measure blood pressures serially, by a noninvasive method, during customary daily activities. These devices, either subject-activated or fully automatic, have been used to identify hypertensive patients who require antihypertensive treatment.

The present study was designed to assess the degree of accuracy of blood pressure readings that can be achieved using the Remler M 2000 blood pressure recorder, a semiautomatic apparatus. In unselected, untreated subjects, we investigated whether blood pressure levels measured by physicians at their offices are representative of those recorded in the ambulatory patient. In addition, in a majority of the volunteers the reproducibility and variability of both office and ambulatory blood pressures were tested over a 3- to 4-month interval.

Subjects and Methods

Subjects
We recruited 101 volunteers (67 men and 34 women) from among the staff of an insurance company. They were aged 41.6 ± 13.3 years (mean ± 2 sd) and their weight averaged 70.1 ± 11.3 kg. No debilitating illness was revealed by past medical history. Only treated hypertensive patients and subjects given drugs known to possibly interfere with cardiovascular homeostasis were excluded (24 of a total of 125).

Instrumentation

Blood pressure was measured indirectly using a mercury sphygmomanometer as well as a semiautomatic portable recorder (Remler M 2000, Remler Corporation, San Francisco, California). This apparatus consists of a standard, patient-inflatable arm cuff, a microphone, a pressure transducer, and a tape recorder. The latter two are contained in a case weighing 0.7 kg, which is attached to the subject with a belt. Each volunteer was instructed to remain still during blood pressure recording (approximately 30 seconds) and to keep the arm extended to avoid generating artifactual
noises. A decoding unit (Remler M 3000, Remler Corporation) was used to read out blood pressure levels from the magnetic tape. The tracing obtained displayed the Korotkoff sounds. During the decoding, these sounds were checked through a headphone in order to screen for possible artifacts. Diastolic blood pressures measured by auscultation with a stethoscope as well as with the portable device corresponded to the fifth Korotkoff sound. It was also possible to derive pulse rate from the tracing. This Remler system was used according to recommendations established previously, and decoding was always performed by the same nurse.

**Procedures**

Initially, three blood pressures (two with subjects sitting and one upright) were measured by the same physician in an office at the worksite when examining the subjects for the first time and again 3 to 4 months later after completion of the study. These blood pressures were measured at 2- to 5-minute intervals by the conventional auscultatory method and are referred to below as “office blood pressures.” Within 1 to 2 weeks after the initial visit the subjects were required to wear the portable recorder. The study nurse fitted the recorder to each volunteer at 8 a.m. Three blood pressure readings in the sitting position were simultaneously determined with the recorder and by direct auscultation using a mercury column temporarily connected to the inflation system. Thereafter, the subjects returned to their usual daily work and activated the recorder at 30-minute intervals for 12 hours. Approximately two-thirds of the readings were taken with the subjects sitting and one-third upright. These are referred to below as “ambulatory blood pressures.” In 84 subjects, the same procedure was repeated 3 to 4 months later. Subjects were told the results of all blood pressure measurements only at the end of the last office visit.

In our experience based on close to 2000 ambulatory blood pressure recordings with the Remler M 2000 system, only 3% to 4% of the recordings could not be used at all. In a vast majority of all recordings, every single blood pressure measurement was interpretable. If uninterpretable measurements occurred, they were usually multiple and related either to equipment failure or noncompliance of the subject.

**Statistics**

Results are reported as means ± standard deviation (SD). Differences between two means were analyzed using Student’s paired t test. Regression coefficients were calculated using the method of least-squares.

**Results**

Figure 1 illustrates the histogram of all mean systolic (left panel) and mean diastolic (right panel) blood pressures obtained during the first recording with the Remler in the 101 volunteers studied. A total of 2512 readings was analyzed. The average of these blood pressures was 117/73 ± 16/13 mm Hg.

In each subject, the three blood pressures obtained on the first office visit as well as all blood pressures obtained from the ambulatory subject during the first recording were averaged. The difference between the mean office and the mean ambulatory blood pressure was then calculated. Figure 2 illustrates the relationship between this parameter and the office blood pressure.
ure both for the systolic (left panel) and the diastolic (right panel). No correlation was observed between the two sets of values. It appears that blood pressure during usual daily activity was higher than in the office only in a minority of subjects (20%). In fact, ambulatory systolic and diastolic pressures were lower than corresponding office blood pressures by an average of 11 ± 11 mm Hg (p < 0.001) and 10 ± 10 mm Hg (p < 0.001). Whereas 31 subjects had blood pressures greater than 140/89 mm Hg at the office, only nine had such levels on the ambulatory recordings. The absolute levels of blood pressure measured at the office and in the ambulatory state were highly correlated (r = 0.75, p < 0.001 for the systolic and r = 0.69, p < 0.001 for the diastolic pressure).

Figure 3 (left panel) depicts the relationship between the average of the three blood pressures measured at the first office visit and the average of the three blood pressures determined at the second office visit. Systolic and diastolic pressures of each subject are plotted on the same graph. There was a close correlation (r = 0.82/0.79, p < 0.001) between these office blood pressures obtained at a 3- to 4-month interval. The mean blood pressure determined at the first visit (129/82 ± 16/12 mm Hg) was slightly though significantly higher (p < 0.05) than that measured at the second visit (126/80 ± 15/12 mm Hg). Figure 3 (right panel) depicts in a similar fashion the relationship between the average of ambulatory pressures obtained in each volunteer during the first recording and that recorded and calculated 3 months later under the same conditions. The correlation between the two parameters was highly significant (r = 0.82/0.78, p < 0.001). The average of ambulatory pressures for the whole group of subjects was 117/72 ± 15/13 mm Hg the first time and 117/73 ± 15/12 mm Hg the second time.

The difference between office and ambulatory pressures was calculated in each subject from the readings obtained at the beginning and at the end of the study. Figure 4 represents the relationship between these blood pressure differences determined at a 3- to 4-month interval. For both the systolic (left panel) and diastolic (right panel) blood pressure, a significant correlation was found (r = 0.43, p < 0.001 and r = 0.44, p < 0.001 respectively).

The standard deviation of the average of all ambulatory pressures was used to estimate blood pressure variability in each subject. For the systolic pressure, it achieved 11.6 ± 3.2 and 11.1 ± 2.7 mm Hg, and for the diastolic, 8.5 ± 2.2 and 8.6 ± 2.7 mm Hg, at the first and second recordings respectively. A significant correlation (r = 0.37, p < 0.01) between these standard deviations obtained at a 3-month interval was observed only for the systolic pressure.

**Discussion**

High blood pressure has been recognized for many years to represent a major cause of morbidity and mortality. To date, there is strong evidence to suggest that the occurrence of cardiovascular complications may be effectively prevented by lowering blood pressure not only in severely hypertensive patients, but also in mildly hypertensive patients with clinic diastolic pressures as low as 90 mm Hg. However, in an individual subject, it remains difficult to decide, on the basis of blood pressure readings taken at the physician’s office, whether antihypertensive therapy is indicated, particularly when pressure levels are not markedly elevated. Thus, blood pressures determined by a physician in a clinical setting have been found to be generally higher than those obtained at home by the patient, most likely reflecting the influence of emotional stress. Indeed, in the normotensive subject as well as in the hypertensive patient, arterial pressure is known to continually fluctuate over the day, depending on physical activity, psychological stress, and environmental factors. For these reasons, it appears desirable to take into account blood pressures measured during usual daily events in exploring a subject with high office blood pressures.

In the present study, ambulatory blood pressure was investigated using a Remler portable, semiautomatic blood pressure recorder. Until now, practically all information on the accuracy and the usefulness of this device has been published by Sokolow and his collaborators who were actively involved in the development of the apparatus. In our hypertension clinic, ambulatory blood pressures have been routinely monitored only during the last 4 years since this portable recorder has been marketed. From the outset, we were concerned that the accuracy obtained by those particularly well-experienced investigators might not
Figure 4. Reproducibility of the difference between office and recorded blood pressures determined at a 3- to 4-month interval in 84 untreated volunteers. Left: systolic blood pressure. Right: diastolic blood pressure.

be reproducible in other clinics. The data reported here clearly demonstrate, however, that the Remler also gave reliable blood pressure profiles in our study. In our volunteers, only minor differences (mostly within -4 and +4 mm Hg) were observed between blood pressure readings determined simultaneously by this device and direct auscultation.

Obviously, blood pressure levels obtained in our volunteers recruited among the employees of a large insurance company may not absolutely reflect those of a random population since our collective undoubtedly contained a majority of subjects with mostly sedentary activities. As previously reported by Sokolow's group, the average systolic and diastolic pressure throughout the day was significantly lower than corresponding office blood pressures. This was also true when ambulatory and office pressures were compared after a 3- to 4-month interval. Interestingly, the difference between office and ambulatory pressures was found to be reproducible over that period of time. In agreement with previous observations is the fact that subjects with respectively the highest and the lowest office blood pressures tended to have the highest and lowest ambulatory pressures. 8, 13

Notwithstanding, in a given individual, it is impossible to predict the ambulatory blood pressure from the office blood pressure, although the average pressure levels recorded with the Remler are approximately 10 mm Hg below office readings for all volunteers taken together. Thus, in 20% of the subjects, the ambulatory pressure was actually higher than the office pressure and, in as many as 25%, it was more than 20 mm Hg below the office blood pressure. It is of note that monitoring of intraarterial pressure has also revealed lower pressure levels outside the clinic and that it is impossible to predict intraarterial ambulatory pressure from office readings. 4

Individual ambulatory as well as office blood pressures were very well reproducible over a period of 3 to 4 months. These data are rather surprising since the variability of office blood pressures from one visit to the other has been stressed in several studies. 23, 24 The excellent reproducibility of office pressures may most likely be explained by the strictly standardized conditions adopted throughout the study when measuring blood pressure by conventional sphygmomanometer. That is, volunteers were examined always by the same physician at the same hour in the morning. In contrast, reproducibility of ambulatory pressures does not depend in any way on environmental medical influences. It should be pointed out that the close agreement between the averages of the two sets of pressures recorded with the Remler occurred even in the face of marked diurnal blood pressure changes. Actually, systolic blood pressure variability, as expressed by the standard deviation of the mean of all pressures recorded by each subject, also tended to be in the same range of magnitude at the first and second ambulatory blood pressure monitoring. Consequently, these findings indicate that the Remler is very useful in assessing ambu-
latory pressure profiles and particularly in detecting subjects with basal blood pressures considerably different from the office readings. Careful blood pressure determination at the clinic by the auscultatory method remains valuable, however, in the long-term follow-up since, based on one Remler recording, it is probably possible to extrapolate the difference between office and ambulatory pressures.

Of the 101 volunteers included in the study, 31 had office blood pressures greater than 140/89 mm Hg whereas only nine had a similar average of all ambulatory pressures. This raises the question of the need of antihypertensive therapy in the subjects who exhibit elevated pressures in the presence of a physician and normal pressures during usual daily activities. One has to remember that the beneficial effect of antihypertensive therapy has been demonstrated in studies carried out in clinics and based on office blood pressure measurements taken by the conventional auscultatory method. Notwithstanding, there is some evidence to suggest that the occurrence of cardiovascular complications is more closely related to ambulatory than of-

it therefore appears reasonable to propose to treat only subjects found to have levels over 140/89 mm Hg during ambulatory blood pressure monitoring. However, further studies are needed to better define indications for antihypertensive therapy based on Remler recordings.

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References
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