Evaluation of the Remler M2000 Blood Pressure Recorder
Comparison with Intraarterial Blood Pressure Recordings
Both at Hospital and at Home

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SUMMARY The Remler M2000 is a semiautomated device that has been used to collect epidemiological data and assess blood pressure variability. It has been subjected to limited evaluation in operation, however, and no studies of its accuracy away from the hospital or office environment have been undertaken. We recruited a group of 28 patients with essential hypertension who were undergoing intraarterial ambulatory blood pressure monitoring and compared the intraarterial recordings with those made with the Remler instrument both at home and in the hospital. The Remler recordings were also compared with simultaneous indirect blood pressure measurements made with the random zero sphygmomanometer. The mean difference between the Remler and intraarterial blood pressure recordings was -3/7 in the hospital and 7/0 at home. All standard deviations were greater than 10 mm Hg, indicating large between-subject variability. Overall, the relationship of the Remler M2000 readings to intraarterial pressures was as close if not closer than standard indirect sphygmomanometry and thus might provide useful data for epidemiological surveys or drug trials. It would appear that for accurate measurement of short-term blood pressure variation and 24-hour recording, intraarterial recording is the method of choice. (Hypertension 6: 209–215, 1984)

KEY WORDS • Remler M2000 • clinic blood pressure • intraarterial ambulatory blood pressure

SELF-recorded blood pressure measurements provide additional information on the behavior of blood pressure away from the hospital environment1 and might aid in the diagnosis of borderline hypertensives.2 The method has also been used to measure blood pressure reduction at different times of the day3 in response to therapy. Like all indirect techniques, the method is open to criticism on the grounds that the patients have been highly selected to ensure the accuracy of recording and that they may not read the blood pressure as carefully away from the supervising physician. For these reasons, automated or semiautomated blood pressure recorders have been developed, several of which have been evaluated and found to be of limited accuracy.4,5

The Remler M2000 (Remler Company, Brisbane, California) is one such instrument that has been used to provide important epidemiological data and information on blood pressure variability.5–8 This recorder has been subjected to only limited evaluation; comparisons have been made with standard indirect methods,9–12 and with intraarterial measurements in only two patients.10 No validations have been undertaken away from the observing physician in the patient’s normal environment. We have used the Oxford system13,14 for intraarterial recording and the Hawkesley random zero sphygmomanometer to evaluate the accuracy of the Remler M2000 blood pressure recorder and M3000 decoder over a wider range of test conditions.

Patients and Methods

Patients
Twenty-eight patients undergoing intraarterial ambulatory blood pressure monitoring during clinical trials volunteered to wear the Remler M2000 for 1 day. These patients gave informed consent, and the project was approved by the Hospital Ethical Committee. They comprised seven women and 21 men, with a mean age of 50 years (range, 23–67 years). Ten patients were receiving therapy: three with a beta-adrenergic blocker/diuretic combination, two with prazosin,
two with verapamil, two with a beta-adrenergic blocker/prazosin combination, and one patient with nadolol. For one comparison there were missing data, and another data set was rejected because of the poor quality of the intraarterial recordings. The results were thus calculated from 26 patients.

**Description of Recording Systems**

**Remler M2000 Pressure Recorder and M3000 Decoder**

The Remler M2000 is a semiautomatic blood pressure recording system. The equipment is portable and is attached to the patient by the observing physician. A microphone is taped over the brachial artery at the point of maximal pulsation but above the antecubital fossa. The blood pressure cuff is applied in the usual position over the microphone, which plugs into the blood pressure recorder. The signal is recorded on a microcassette tape recorder. The subject inflates the cuff using a standard inflation bulb, and at a preset level, which is above the systolic pressure, the equipment is switched on, as indicated by a red light. The pressure leaks automatically as calibrating pulses and arterial sounds are recorded on magnetic tape, until the red light is extinguished when a low pressure pneumatic switch automatically turns off the recorder. The time taken for the whole procedure is approximately 1 minute. The cycle is repeated for each pressure recording, and the signal is recorded on magnetic tape. The blood pressure data recorded on the microcassette cartridge is translated via the M3000 decoder into a permanent graphic display on chart paper, from which the blood pressure level is measured.

**The Oxford System for Intraarterial Blood Pressure Monitoring**

This system has been well described in earlier reports, as have its limitations. The system has a known frequency response flat to 10 Hz, which is adequate for blood pressure measurement but not for analysis of wave form.

**Protocol**

The intraarterial monitoring equipment was attached to the patients, as described previously, and then the Remler M2000 was fitted to the dominant arm. The intraarterial blood pressure signal was relayed directly via a junction box to a chart recorder (Techmation, Edgware, Middlesex, England) and simultaneously to the Medilog tape recorder (Oxford Instruments, Oxford, England). The system was calibrated using a mercury sphygmomanometer.

**Clinic Measurement**

To compare clinic measurements with the Remler recordings, the Remler blood pressure cuff was linked via a Y connector to a Hawkesley random zero sphygmomanometer (Gelman Ltd., Lancing, Sussex, England) and the Remler M2000 recorder. Three separate recordings were made at 5-minute intervals. During each recording, one observer auscultated over the brachial artery and read the pressure from the random zero sphygmomanometer. This observer marked the intraarterial traces when the red light appeared, indicating that the Remler M2000 was switched on, and also marked Korotkoff sounds I and V. During this procedure, the leak-off valve on the Hawkesley was switched off, and the leak rate was controlled by the Remler M2000. The output from the microphone was monitored by a second observer using the Remler M3000 headset. This observer marked the Korotkoff sounds I and V auscultated via the head set on the Remler blood pressure trace. The Remler decoder was then detached from the recorder, and the transducer/perfusion unit of the intraarterial system reconnected directly to the Medilog tape recorder. Before the patients returned to their normal environment, they were given clear instructions on how to use the Remler M2000.

**Home Measurements**

While they were sitting down, patients inflated the blood pressure cuff until the red light appeared. They then pressed the event marker of the intraarterial recording system. They specifically kept the cuff arm straight during the recording and recorded the time of the measurement on a diary sheet. They took measurements every hour until they went to bed and again the next morning before they returned to the hospital. At this time the Remler recorder was removed and the microcassette tape decoded. During decoding, an observer auscultated the recorded Korotkoff sounds and marked the Remler chart paper to coincide with Korotkoff I and V sounds. This served as a check of the Remler pen recorder.

Indirect recordings were made on the dominant arm, and the intraarterial recordings were made on the contralateral arm; for this reason a separate study was performed to determine the pressure differences between the arms. Two observers recorded the blood pressure in each arm simultaneously using one random zero sphygmomanometer connected to both cuffs. Duplicate readings were made on each arm, and again after the observers had switched arms. The whole procedure was repeated after switching cuffs, so that there was a total of eight paired readings.

**Data Analysis**

A hybrid computer was used to calculate hourly mean values from the direct recordings, and a 1-minute-average blood pressure value corresponding to each indirect measurement was extracted from the recordings. The reliability of this 1-minute-average value has been reported previously. The pressures recorded by the Remler M2000 at home and in the hospital were compared with each other and with the simultaneous intraarterial 1-minute-average value. Remler M2000 pressures for each patient were averaged over the day of the intraarterial monitoring, and the mean daytime intraarterial pressure was calculated by processing measurements of the blood pressure in hourly sections and averaging the means of each hour between 0800 and 2000 hours.
Each comparison of two methods included a scatter plot and a histogram of the between-method differences using the data from one recording only. Comparisons of the two methods also included paired $t$ tests, but it is the variability of the differences between the methods that is of greatest clinical relevance. A small mean difference (2 mm Hg) might be statistically significant but would be of no clinical importance. Only the lines of identity were plotted; regression lines and correlation coefficients were not calculated because the correlation coefficient is a measure of association, and by definition, the different methods of recording the blood pressure are bound to be associated.\(^7\) Analysis of variance was used to analyze the between-arm differences in blood pressure.

**Results**

**Interarm Difference in Blood Pressure (Mean of Eight Readings)**

The mean difference (right-left) was 0.1 (SE 0.8)/-0.4 (SE 0.5) mm Hg. Neither difference was statistically significant. For 24 patients, the mean systolic difference was less than 5 mm Hg, and only four had a mean difference between 6 and 10 mm Hg. Only one patient had a mean diastolic difference between 6 and 10 mm Hg, the rest being less than 5 mm Hg.

**Comparison of Blood Pressures Measured at Home**

Individual Remler blood pressure readings were compared with the simultaneous 1-minute-average intraarterial pressures (Figure 1), and the average of the daytime Remler readings was compared with the mean daytime intraarterial pressure (Figure 2). The mean differences were small (Table 1) except for the comparison of the Remler system with intraarterial monitoring at home for systolic pressures. In both cases there was considerable variation among subjects, as shown by the standard deviations of individual differences (Table 1) and by the scatter in the figures.

Each patient recorded the blood pressure once each hour, and this pressure was compared with the average intraarterial pressure for the same hour (Figure 3), using paired $t$ tests (two-tailed). There was good aver-
### Table 1. Comparison of Blood Pressure Measurements Recorded with the Remler M2000, Intraarterial Monitoring, and Random Zero Sphygmomanometer

<table>
<thead>
<tr>
<th>Blood pressure</th>
<th>No. of patients</th>
<th>Comparison</th>
<th>Mean (mm Hg)</th>
<th>SD (mm Hg)</th>
<th>Difference between methods (mm Hg)</th>
<th>SD of difference (mm Hg)</th>
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<th>p</th>
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<td>Individual</td>
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<td>Remler</td>
<td>165</td>
<td>28.0</td>
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<td>28.9</td>
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<td>24.7</td>
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<td>7</td>
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IABP = intraarterial ambulatory blood pressures; CBP = clinic blood pressures.

Complications and Nonanalyzable Data

*Remler M2000 Recorder*

Ten percent of the Remler 2000 recordings could not be analyzed for the following reasons:

1. Flexion of the arm during the recording distorted the calibration points (6%).
2. The system failed to record the Korotkoff sounds (4%).
3. The blood pressure of one patient was at times too high to be recorded (the Remler cannot record pressure above 250 mm Hg).

*Intraarterial Ambulatory Blood Pressure Monitoring*

An internal audit of 1000 cases of ambulatory blood pressure monitoring and 35 cases where cannulation failed revealed that there was only one serious complication. An infected hematoma at the cannulation site led to the formation of a false aneurysm and resulted in the ligation of the brachial artery (but no loss of arm function). There were 157 minor complications in 122 studies, including hematoma (48 cases), hemorrhage...
EVALUATION OF REMLER M2000/Gould

FIGURE 3. Hourly trend plot of Remler blood pressure (BP) readings (○) and intraarterial BP readings (●). At the top of the graph, n indicates the number of patients from which the values were derived. ----, p < 0.05; ------, p < 0.01.

FIGURE 4. Scatter plot and frequency histogram of blood pressure (BP) measurements taken in the hospital by the Remler M2000 compared to intraarterial BP hospital measurements. The frequency histogram shows that 65% of the systolic BP readings were within ±10 mm Hg, and that 42% of the diastolic BP readings were within ±10 mm Hg.

Discussion

Various workers have compared “one off” clinic blood pressure with intraarterial pressures16–29 and have shown considerable differences between the values obtained. Epidemiological and insurance data are based largely on “one off” recordings of the blood pressure, but these data can only hold good for large populations. Attempts have been made to try to improve the diagnostic accuracy of the measurement for individuals, as not all patients with a single elevated blood pressure reading will have elevated readings on subsequent occasions. Home blood pressure recordings have been employed to determine those patients requiring therapy, using either self-recorded pressures or automated recorders to improve accuracy and avoid patient digit preference.

The Remler M2000 recorder has been used extensively to measure blood pressure changes away from the hospital environment27 as well as to assess the role of ambulatory blood pressure monitoring and to predict those patients who are subject to the morbidity associated with hypertension.29 The monitor is expensive but individual readings are cheap, and serial studies may be undertaken on a large number of patients over several years. This recorder has been subjected to limited testing in the laboratory but has not been assessed away from the hospital environment. This study was designed to provide a detailed laboratory assessment as well as an evaluation of the recorder in the patient’s normal environment.

Our data showed that, in general, the Remler M2000 provided records that reflected the blood pressure of a group of patients reasonably well, but the standard deviation about the mean discrepancy was large, indicating that a single reading for an individual may be inaccurate. The variation in the differences was larger than can be accounted for by the variability of intraarterial blood pressure measurements. Use of the aver
age of several measurements of the blood pressure might yield a more accurate assessment. The data suggest that systolic blood pressures recorded by the Remler at home overestimated the intraarterial pressure to a greater extent than those made in the hospital. The diastolic pressure showed considerable overestimation of the intraarterial blood pressure when recorded in hospital. It can be seen that there was wide individual variability, with the standard deviations about the mean difference generally exceeding 10 mm Hg (Table 1).

When results of the Remler M2000 method were compared with those of the standard clinic method, there was a small mean difference, but again, the standard deviation about this difference was large, indicating considerable individual variability. These results are similar to those described by Harry and Young. The discrepancy between the Remler M2000 and the standard mercury sphygmomanometer was 3 (sd 9)/5 (sd 14) mm Hg in the supine position. Beever et al. reported similar results, with a mean difference of 8.3/8.1 mm Hg comparing the Remler with the Hawkesley random zero sphygmomanometer and of 7.4/10.4 mm Hg when comparing it with the London School of Hygiene sphygmomanometer. These results agree well with those described here. In contrast, the mean discrepancies reported by Cowan et al. were 0.06/0.24 mm Hg, with minimal variability. Nearly all points in their scatter plots fell along the lines of identity, unlike an earlier evaluation by Hinman et al. in which there was greater individual variability. The mean difference reported by Hinman et al. was 2/4 mm Hg, but the individual differences ranged from −30 to +20 mm Hg for systolic pressures and from −10 to +20 mm Hg for diastolic pressures. The near-perfect agreement reported by Cowan et al. is hard to explain, since no other comparison study of two indirect methods of blood pressure measurements has shown such good agreement. It might be argued that Cowan et al. were regular Remler users and might therefore be expected to have obtained better results than the occasional user. Another explanation may simply be random variation. Since several other studies have yielded results similar to ours, this explanation is unlikely to be correct.

Taking all studies into consideration, we find that the Remler pressures agree reasonably well with clinic pressures, although there occasionally are wide individual differences. Both these indirect techniques show a similar level of agreement with the intraarterial...
pressures. The Remler M2000 is likely to show what happens in a group of patients (as in trials of antihypertensive agents), but when managing an individual patient the true blood pressure may differ widely from that indicated by the Remler M2000. Of course, the accuracy would improve if serial and replicated readings were obtained.

The Remler M2000 can only provide intermittent readings measured during the daytime period while the subject ceases all activity. Although these readings may relate to prognosis in terms of morbidity and mortality, they cannot reflect the rapid changes or spontaneous blood pressure fluctuations that occur during physiological maneuvers. It is known that at the end of exercise, for example, the blood pressure falls extremely rapidly and that it is impossible to measure it accurately except by intrarterial methods. Nor can the Remler instrument measure blood pressure during sleep. Intrarterial monitoring provides a continuous record of the blood pressure throughout 24 hours and can assess responses to various external or physiological stimuli, but it is invasive, time-consuming, and confined to a relatively small number of patients. It is inappropriate for large epidemiological surveys, whereas the Remler could provide useful information.

We conclude that evaluation of short-term blood pressure patterns and responses to exertion and sleep are best undertaken by intrarterial monitoring, whereas epidemiological surveys and drug trials might be conducted with the Remler M2000 and M3000 decoder, especially if the mean of several observations is used.

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