Continuous vs Intermittent Blood Pressure Measurements in Estimating 24-Hour Average Blood Pressure

MARCO DI RENZO, PH.D., GUIDO GRASSI, M.D., ANTONIO PEDOTTI, PH.D., AND GIUSEPPE MANCIA, M.D.

SUMMARY In the past few years noninvasive automatic blood pressure (BP) recorders have been increasingly used to estimate patients' 24-hour BP more accurately than by one or few isolated measurements. However, these recorders only allow BP to be intermittently measured at intervals between 5 to 30 minutes, which means that the number of values collected over 24 hours (10 to 100) remains a tiny fraction of the thousands of values that occur during the same period. To determine whether this represents a limitation to this approach, BP was recorded intraarterially for 24 hours (Oxford method) in 20 ambulant hypertensive patients. A beat-to-beat analysis of the BP recording was provided by a computer, and the average 24-hour systolic, diastolic, and mean BP values were compared with those obtained by analyzing single BP waves of the same recording at intervals of 5, 10, 15, 30, and 60 minutes. In each subject the average 24-hour BP values obtained by the beat-to-beat analysis closely corresponded to those obtained by the analysis performed at 5-, 10-, 15-, or 30-minute intervals. In most subjects, this was the case also when the analysis was performed at 60-minute intervals. These findings demonstrate that intermittency of measurements does not limit the accurate assessment of true average BP. Indeed, accurate assessment can be achieved at intervals as much as 30 or 60 minutes apart. (Hypertension 5: 264-269, 1983)

KEY WORDS • blood pressure variability • automatic blood pressure recording • intraarterial blood pressure recording

In recent years noninvasive automatic blood pressure recorders have been developed in an attempt to record blood pressure more accurately than has been possible with instruments affording isolated measurements often collected under psychologically unfavorable conditions. Most of these new recorders still present limitations with regard to accuracy. Also, there are problems with the intermittency of the readings, usually at intervals of 5 to 30 minutes, which means a maximum of a few hundred values in 24 hours. This number is a minute fraction of the many thousand values that make up a 24-hour blood pressure profile. Our study investigates whether this limitation affects the accuracy of the results.

Methods

Our study was performed on 20 hospitalized subjects all with uncomplicated untreated essential hypertension of mild or moderate degree. In each subject arterial blood pressure was invasively recorded for 24 hours with the Oxford technique, the arterial cath-

Table 1. Age, Sex, 24-Hour Mean Arterial Pressure (MAP), and Standard Deviation for MAP (SD) in 20 Subjects

<table>
<thead>
<tr>
<th>No.</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>MAP (mm Hg)</th>
<th>SD (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45</td>
<td>M</td>
<td>110.7</td>
<td>9.9</td>
</tr>
<tr>
<td>2</td>
<td>52</td>
<td>M</td>
<td>144.5</td>
<td>17.2</td>
</tr>
<tr>
<td>3</td>
<td>41</td>
<td>M</td>
<td>105.2</td>
<td>12.8</td>
</tr>
<tr>
<td>4</td>
<td>29</td>
<td>F</td>
<td>108.3</td>
<td>19.4</td>
</tr>
<tr>
<td>5</td>
<td>51</td>
<td>M</td>
<td>100.5</td>
<td>15.4</td>
</tr>
<tr>
<td>6</td>
<td>36</td>
<td>F</td>
<td>103.9</td>
<td>14.5</td>
</tr>
<tr>
<td>7</td>
<td>24</td>
<td>M</td>
<td>100.3</td>
<td>11.5</td>
</tr>
<tr>
<td>8</td>
<td>48</td>
<td>F</td>
<td>113.9</td>
<td>18.5</td>
</tr>
<tr>
<td>9</td>
<td>43</td>
<td>F</td>
<td>119.3</td>
<td>18.3</td>
</tr>
<tr>
<td>10</td>
<td>63</td>
<td>M</td>
<td>97.5</td>
<td>12.9</td>
</tr>
<tr>
<td>11</td>
<td>50</td>
<td>M</td>
<td>130.4</td>
<td>18.4</td>
</tr>
<tr>
<td>12</td>
<td>33</td>
<td>M</td>
<td>92.0</td>
<td>16.2</td>
</tr>
<tr>
<td>13</td>
<td>43</td>
<td>F</td>
<td>117.5</td>
<td>15.7</td>
</tr>
<tr>
<td>14</td>
<td>42</td>
<td>M</td>
<td>188.5</td>
<td>15.3</td>
</tr>
<tr>
<td>15</td>
<td>38</td>
<td>F</td>
<td>105.6</td>
<td>13.9</td>
</tr>
<tr>
<td>16</td>
<td>47</td>
<td>M</td>
<td>130.5</td>
<td>17.1</td>
</tr>
<tr>
<td>17</td>
<td>54</td>
<td>M</td>
<td>100.3</td>
<td>10.8</td>
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<tr>
<td>18</td>
<td>38</td>
<td>F</td>
<td>76.7</td>
<td>12.3</td>
</tr>
<tr>
<td>19</td>
<td>45</td>
<td>M</td>
<td>83.9</td>
<td>12.4</td>
</tr>
<tr>
<td>20</td>
<td>68</td>
<td>F</td>
<td>140.5</td>
<td>10.7</td>
</tr>
</tbody>
</table>

MAP refers to the average 24-hour values obtained in each subject by continuous analysis of the direct blood pressure recording. SD also refers to data obtained by continuous analysis.

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eter being implanted percutaneously in a radial artery. During the recording the subjects were free to move within the hospital area and to engage in recreational and social activities as inpatients not confined to bed.

Each recording was analyzed by a computer (PDP 11/34) that sampled the blood pressure signal every 60 msec and calculated for each pressure wave the systolic, diastolic, and mean arterial pressures. These values were stored on a magnetic disk to be later analyzed by two different methods. First, the average systolic, diastolic, and mean arterial pressures were calculated for the whole 24-hour recording period by making use of all available values, i.e., the values of all pressure waves. Second, the average systolic, diastolic, and mean arterial pressures over 24 hours were also calculated by making use of the data of single pressure waves regularly taken at intervals of 5, 10, 15, 30, or 60 minutes. The results obtained by this latter method, which simulated intermittent blood pressure measurements, were compared with those obtained by the former method in which measurements were virtually continuous.

In each subject, calculation of average 24-hour systolic, diastolic, and mean arterial pressures was ac-

![Figure 1](http://hyper.ahajournals.org/)

**FIGURE 1.** Evaluation of the average 24-hour systolic blood pressure (SBP) value obtained by taking into account all SBP values in the 24 hours and by considering SBP values at intervals of 5, 10, 15, 30, and 60 minutes throughout the same period of time. The results obtained via the second method of analysis (indicated by the points) are shown as differences from the result obtained via the former method of analysis (indicated by the dashed horizontal line intersecting the 0 point). Data from the 20 subjects are separately shown.
accompanied by calculation of their respective 24-hour standard deviations. Also, in this instance a comparison was made of the results obtained through continuous and variably intermittent analyses of the data. In this way it was possible to assess whether intermittent blood pressure measurements could evaluate blood pressure variability precisely, a phenomenon that is important for understanding cardiovascular regulation\textsuperscript{16-18} and which may also represent an independent risk factor in hypertension.

The results were separately analyzed for each patient and also calculated as means (± SE) for the whole group of patients. Before performing the 24-hour blood pressure recording, all patients gave free and informed consent to the procedure.

Results

The average 24-hour mean arterial pressure obtained in each subject by continuous analysis of the 24-hour recording is shown in table 1. Comparison of the data obtained by the continuous and intermittent measurements of the blood pressure tracing are shown in figures 1, 2, and 3. In each patient the intermittent measurements provided average values for systolic, diastolic, and mean arterial pressure that were close (and often identical) to those obtained by the continuous measurements. This occurred when the intervals between the intermittent measurements were set at 5, 10, or 15 minutes, and also (with a slightly greater approximation) when the intervals were set at 30 minutes. Even prolongation of the intervals to 60 minutes

\[ \Delta \text{DBP} \]

\[ \text{mm Hg} \]

\[ +10 \]

\[ 0 \]

\[ -10 \]

\[ +10 \]

\[ 0 \]

\[ -10 \]

\[ +10 \]

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caused only small differences to appear in only few subjects. When expressed as average data for all patients (fig. 4), the 24-hour readings provided by the intermittent measurements at 60-minute intervals differed from those obtained through continuous measurements by no more than 2–3 mm Hg. For the intermittent measurements at shorter intervals, these differences were 1 mm Hg or less.

The results obtained for mean arterial pressure variability are shown in table 1 and figure 5, which compare the data obtained by continuous and intermittent measurements. The 24-hour standard deviations of mean arterial pressure that were obtained by intermittent and continuous measurements differed much more than the average 24-hour mean arterial pressure values. When the intervals between the intermittent measurements were 5, 10, or 15 minutes, the differences with the data obtained by continuous measurement were in the range of ± 10%. When the intervals were of 30 or 60 minutes, the differences remained within a similar range in a number of subjects, but when the intervals were 24 hours, the differences increased in a number of patients, to produce erratic results. Similar results were obtained for standard deviations of systolic and diastolic blood pressure.

Discussion

Our observations demonstrate that over a 24-hour period the average blood pressure values from measurements at intervals from 5 to 30 or 60 minutes do not...
FIGURE 4. Mean (± SEM) data for SBP, DBP, and MAP obtained from the individual data shown in figures 1, 2, and 3. Explanations as in the preceding figures; 24-hour average (± se) values for systolic, diastolic, and mean arterial pressure obtained by analysis of all values were, respectively, 174.5 ± 6.7, 101.2 ± 3.4 and 125.4 ± 4.3 mm Hg.

FIGURE 5. Evaluation of 24-hour standard deviation for MAP obtained by taking into account all pressure values in the 24 hours, and by considering only the pressure waves occurring at intervals of 5, 10, 15, 30, and 60 minutes. The results obtained via the second method of analysis are shown for each subject as absolute (left panel) and percent (right panel) differences from those obtained via the former method of analysis (for each subject represented by the dashed horizontal line intersecting the 0 point). The 24-hour average (± se) standard deviation for MAP was 15.1 ± 1.1 mm Hg.
differ substantially from mean values obtained by continuous measurement. This finding implies that a large number of blood pressure values are not necessary to achieve accurate mean values, a factor that may considerably reduce the complexity and cost of computer programs and facilities. Also, and more important, these results reinforce the use of noninvasive techniques that enable blood pressure levels to be automatically assessed at selected intervals. The accuracy of the single blood pressure readings provided by these devices is still under scrutiny. However, it is important that intermittency of blood pressure assessment does not itself represent a limitation in estimating the true average blood pressure of patients. It is also important that such an assessment can be obtained even by increasing the interval of the sampling up to 30 or 60 minutes. This may justify future adoption of automatic blood pressure measurements more widely spaced, with less disturbance to the patient. It may also simplify the construction of the recorders and avoid some technical difficulties.

With regard to the second issue of our study, the standard deviations of the 24-hour blood pressure values were also not too different when derived by intermittent blood pressure measurements or by continuous blood pressure analysis. However, for intervals of measurements of 5 to 15 minutes, these differences encompassed a range of ±10%, and this was much more than the ±1% to 2% difference found for the mean blood pressure values. Furthermore, in a number of subjects (about 30%) the differences in the standard deviation for blood pressure became larger, and often much so, for intermittencies of 30 or 60 minutes. This may be explained simply in statistical terms: according to the inference formulas, when the sampling size is reduced the potential error in estimating the true variance of the population under study progressively increases, and the rate of this increase largely exceeds that which characterizes the error in estimating the mean of the same population. At any rate, it is clear that intermittent blood pressure measurements may assess blood pressure variability less precisely than is the case with mean blood pressure values. In particular serious errors may occur if blood pressure assessments are too far apart from each other.

References

Continuous vs intermittent blood pressure measurements in estimating 24-hour average blood pressure.
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