Arterial Blood Pressure Measurements with a Portable Recorder in Hypertensive Patients

I. Variability and Correlation with "Casual" Pressures

By Herbert K. Kain, M.D., Allen T. Hinman, M.D., and Maurice Sokolow, M.D.

The clinical significance of the "casual" arterial blood pressure level recorded in a physician's office or in an outpatient clinic is often difficult to interpret. As most physicians are aware, such casual readings may not be representative of the patient's usual blood pressure. Clinical investigators have therefore measured the blood pressure in a variety of circumstances in the hope of acquiring more meaningful information about its range and variability. In addition to frequently repeated casual pressures, they have examined "basal" pressures, pressures taken at home either by the patient or a member of his family, and pressures taken after breath-holding, during cold pressor tests, and after mental arithmetic or other stimuli. Although the data obtained contribute to a broader and more dynamic picture of the blood pressure, the conditions of each study are more or less artificial; thus, the recorded pressures may not reflect the patient's pressure levels during normal daily activity.

Recently, Hinman and associates developed a semiautomatic portable blood pressure recorder that a patient can wear with little inconvenience while going about his usual routine. The pressure cuff is placed on the upper arm and the electronic equipment and battery are worn at the waist (fig. 1).

This technical achievement has permitted a study, heretofore unfeasible, of variations in a human subject's blood pressure under the usual stresses of daily living.

Subjects and Methods

Subjects for this study were selected from patients who had been referred to the Hypertension Clinic for routine evaluation. Criteria for selection included willingness to wear the portable recorder daily, preferably for a 12-hour period, for 3 consecutive days, and in the case of patients under treatment the feasibility of discontinuing antihypertensive medications for 2 weeks before the study was begun. Severely hypertensive patients were excluded, since it was considered advisable to stop their medications or to delay their admission to the hospital for further treatment.

The final study group consisted of 62 patients, 22 men and 40 women, averaging 44.5 years in age, who had hypertension of mild to moderate severity as classified by the criteria of Sokolow and Perloff (table 1). The average casual pressure of the group was 170.6/104.3 mm Hg. All of the patients recorded their blood pressures with the portable apparatus 35 times or more; 26 of the patients wore the recorder 12 hours daily for 3 successive days, and 36 wore it for 2 successive days.

Portable Blood Pressure Recorder

The recorder, consisting of a standard sphygmomanometer cuff, microphone pick-up, pressure transducer, twin signal lights, and magnetic tape-recording device, was designed to be worn by the subject during his daily activities (fig. 1). Several improvements in equipment have been made since the results of preliminary studies with the recorder were reported. The unit containing the electronic components has been re-

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* The improved portable recorder used in this study was assembled by the Remler Company, 2101 Bryant Street, San Francisco, California 94110.
duced from 36 to 16 cubic inches in size and from 2.1 to 0.8 pounds in weight; the entire portable apparatus now weighs 4.8 pounds, instead of 5.5 pounds. The microphone, which formerly was placed in the antecubital space, is now placed over the brachial artery under the lower part of the blood pressure cuff, a location more comfortable for the patient. According to Blaquier and Hoobler, placement of the stethoscope in this position does not affect the accuracy of the readings. The mechanics of recording blood pressure levels with the portable machine have been described previously.17

Experimental Procedure

Each patient was asked to report to the laboratory at 8:00 a.m. on 2 or 3 successive days. The following routine was carried out each morning. The portable recorder was adjusted to a comfortable position on the patient; the pressure cuff was then taped in place. For the purpose of calibration, a blood pressure manometer was temporarily introduced into the inflation system by means of a Y-connector. The cuff was inflated to 250 mm. Hg and then allowed to deflate automatically; each 10-mm. fall in pressure noted on the manometer was designated by a finger tap on the microphone. These sounds, at appropriate pressures, allowed calibration of the “read-outs” on the graphic pen recorder (fig. 2). Immediately thereafter, the blood pressure level was determined simultaneously with the portable recorder and by the usual auscultatory method. Three such readings were taken in succession; the manometer was then disconnected. The patient left

Table 1

<table>
<thead>
<tr>
<th>Grade of Vascular Involvement</th>
<th>Men</th>
<th>Women</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 0-I</td>
<td>17</td>
<td>26</td>
</tr>
<tr>
<td>Class II</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Class III</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Class IV</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

* Based on criteria of Sokolow and Perloff.18

Figure 1

Left. Portable blood pressure recorder in use. Subject’s left arm is extended in optimal recording position, while right hand operates the inflating bulb; the recorder itself is concealed by suit jacket. Right. The equipment consists of arm cuff, inflating bulb, signal lights (clipped to blouse), a case containing the electronic components (on subject’s left), and a case containing the tape recorder (on subject’s right). The cases can be moved to any position on the belt as required for comfort or changes in posture.
the laboratory and returned to his normal daily routine. He was instructed to record his pressure every 30 minutes during the day and was supplied with an interval-timer to remind him to do so. The patient removed the portable recorder at home 12 hours later and placed it in a carryall bag provided for the purpose. When he returned to the laboratory the next morning, the recorder was replaced and again calibrated in the manner described.

The average "casual" pressure of each subject was established by averaging all pressure levels (three or more) recorded in the Hypertension Clinic before the study period. The readings, taken by auscultation by a physician after the patient had been sitting for some time in the waiting room or examining room, are representative of the "casual" pressures usually obtained in an outpatient clinic or physician's office.

The data on each subject were coded on an IBM card. An IBM-7090 computer was programmed in compiling the data and performing statistical analyses.

**Results**

**Agreement between Blood Pressure Levels Determined with Portable Recorder and by Auscultation**

The accuracy of measurements taken with the portable recorder* was evaluated as follows. The average of the three pressure readings taken by auscultation and the average of the three pressures taken simultaneously with the portable recorder at the beginning of each day were calculated for each subject. The difference between the two sets of values was then determined. A difference greater than 10 mm. Hg was found in only one patient; he was therefore not included in the study group. When the pressures of the remaining 62 subjects were averaged, the average differences (neglecting sign) were negligible; the systolic pressures averaged 160.9 mm. Hg by auscultation compared with 160.5 mm. Hg by the portable recorder. The average diastolic pressure of the group was 99.6 mm. Hg by auscultation and 98.6 mm. Hg by portable recorder. The differences were as slight at higher pressures as they were at lower pressures.

**Data on Portable Recorder Measurements in 62 Hypertensive Patients**

The computer data on the recorded pressures, including the mean of the five highest and the mean of the five lowest readings during the 2- or 3-day period, are summarized in table 2. Five readings were averaged to obtain figures for the high and low pres-

* For convenience, the blood pressure levels taken with the portable recorder will be referred to as recorded pressures or levels.
Table 2

Computer Data on Blood Pressure Measurements Obtained by Portable Recorder in 62 Hypertensive Patients

<table>
<thead>
<tr>
<th>Variable</th>
<th>Systolic pressure*</th>
<th>Diastolic pressure*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average of all</td>
<td>158.4 ± 19.1</td>
<td>94.7 ± 13.1</td>
</tr>
<tr>
<td>pressures recorded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of all pressures</td>
<td>14.1 ± 4.3</td>
<td>9.0 ± 2.1</td>
</tr>
<tr>
<td>recorded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>63.7 ± 17.2</td>
<td>42.4 ± 8.7</td>
</tr>
<tr>
<td>Mean of 5 highest pressures</td>
<td>185.0 ± 22.5</td>
<td>111.9 ± 13.0</td>
</tr>
<tr>
<td>Mean of 5 lowest pressures</td>
<td>135.0 ± 16.8</td>
<td>79.6 ± 12.1</td>
</tr>
<tr>
<td>Average of all</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“casual” pressures</td>
<td>170.6</td>
<td>104.3</td>
</tr>
</tbody>
</table>

* Values are means ± standard deviations of the means of the pressures recorded by the 62 patients during the 2- or 3-day study period.

Figure 3

Blood pressure levels recorded with portable recorder and pulse rate during 3 consecutive days. Each point represents the average values for each time period in 26 patients.

Blood pressure readings from day to day and the time required to adapt to wearing the recorder, differences between daily pressures were determined from data on the 26 patients who wore the portable recorder for 3 successive days. From the average of the systolic and diastolic pressures recorded each day by each patient, the average daily group pressures were calculated. As shown in figure 3, both the mean systolic \((p = < 0.025)\) and diastolic pressures \((p = < 0.01)\) were significantly higher on the first day than on the second and third days; the mean pressures on the second and third days, however, did not differ significantly, indicating that adaptation had occurred by the second day. The average pulse rate for the group showed little interdaily change during the 3-day period.

Variations during the Day

To determine the presence of diurnal variation, the daily readings taken by 26 patients were then averaged according to the time of recording: (a) before 11 a.m., (b) from 11 to 2 p.m., (c) from 2 to 5 p.m., and (d) after 5 p.m. Since all subjects did not begin and end the recording period at exactly the same time, the first and last time intervals were not necessarily as long as the intervening periods; in general, however, pressures were taken from 8 a.m. to 8 p.m. As shown in figure 3, the blood pressures of all subjects consistently fell during the first 6 hours the recorder was worn, but generally leveled off after 2

Circulation, Volume XXX, December 1964
p.m. The average pressure between 8 and 11 a.m. was significantly greater than the average pressure after 11 a.m. \( p < 0.02 \) for systolic and \( p < 0.01 \) for diastolic pressure. The fall after 11 a.m. occurred each day, but was most pronounced on the first day. Although there were individual exceptions, the average pressures for the group remained level after 2 p.m. Each day, the percentage drop in diastolic pressure during the first few hours exceeded the percentage drop in systolic pressure. The pulse rate rose slightly when the pressure fell, then decreased gradually throughout the remainder of the day (fig. 3).

**Variability of Blood Pressure**

One of the major purposes of the present investigation was to study the variability of the blood pressure during the day. Variability was determined by calculating standard deviations from the mean of all systolic and diastolic pressures recorded by each patient during the 2- or 3-day period and by determining the range of pressures obtained during the study period. The standard deviation was correlated with various blood pressure indexes as shown in table 3. The data in this table and in figure 4 show a low correlation \( r = 0.34 \) between the average systolic pressure of each patient and variability; no correlation was found between the average diastolic pressure and variability \( r = 0.02 \).

**Table 3**

*Computer Data Showing Correlation between Variability of Blood Pressure Levels Obtained by Portable Recorder in 62 Hypertensive Patients and Various Blood Pressure Indexes and Age*

<table>
<thead>
<tr>
<th></th>
<th>Systolic pressure ( r^* )</th>
<th>Diastolic pressure ( r^* )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pressure</td>
<td>0.34</td>
<td>0.02</td>
</tr>
<tr>
<td>Range</td>
<td>0.96</td>
<td>0.95</td>
</tr>
<tr>
<td>Mean of 5 highest pressures</td>
<td>0.63</td>
<td>0.31</td>
</tr>
<tr>
<td>Mean of 5 lowest pressures</td>
<td>-0.02</td>
<td>-0.25</td>
</tr>
<tr>
<td>Age</td>
<td>0.20</td>
<td>-0.04</td>
</tr>
</tbody>
</table>

* Determined by calculating standard deviations from the mean of all pressures recorded by each patient during the 2- or 3-day study period.

\( r^* = \) correlation coefficient. Values in italics are statistically significant at the 0.01 level.

Figure 4 shows individual instances in which the standard deviation is very large at moderate average pressures and others in which the standard deviation is relatively modest at high average readings. A threefold difference in standard deviation was found in individual patients with an average recorded systolic pressure of 150 to 160 mm. Hg; similar but smaller differences in the standard deviation in individual patients occurred at various diastolic pressures (fig. 4).

**Range**

The difference between the average of the five highest and the average of the five lowest levels obtained during the 3-day period was computed for each person as an estimate of the range of his blood pressure. The range of the diastolic pressures in the hypertensive patients with higher pressures was approximately the same as the range in patients with lower pressures (fig. 5), but the range of the systolic pressures was slightly greater at higher pressures. As would be expected if there was a normal distribution of pressures, the range and the standard deviation of the mean were highly correlated \( r = 0.96 \). The slopes of the regression lines (fig. 5) show only a slight divergence at higher average recorded systolic pressures and no divergence at various average recorded diastolic pressures; it is apparent that the range remains about the same whatever the level of blood pressure.

*Circulation, Volume XXX, December 1964*
Relationship of the highest and lowest pressures to the over-all average pressures for each of 26 patients. The closed dot represents the average of the five highest and the open dot the average of the five lowest pressures taken with the portable recorder; the solid line through the dots is the line of regression.

Variability, therefore, is not closely related to the average recorded blood pressure.

Comparison of “Casual” and Recorded Pressures

Systolic

The relationship of the average casual systolic pressure to the average systolic pressure recorded with the portable apparatus in the 62 patients is shown in figure 6; the two averages are highly correlated (r = 0.73). In general, the recorded pressure levels were lower than the casual pressures; higher levels were recorded in 12 patients (19 per cent) of the group and were almost identical in 6 patients (10 per cent). The relationship between the two averages was not the same in the subjects with lower as in those with higher casual pressures. As can be seen from the divergence of the regression line from the line of identity in figure 6, the higher the average casual pressure, the greater was the difference between it and the average pressure recorded with the portable machine.

Striking individual differences between the average casual and the average recorded pressures were noted. The average recorded pressure varied from 140 to 220 mm. Hg in patients whose casual pressures averaged 190 to 200 mm. Hg and from 120 to 180 mm. Hg in those whose casual pressures averaged 160 mm. Hg.

Diastolic

Similar findings characterized the relationship between the average casual diastolic pressure and the average recorded diastolic pressure (fig. 7). The two averages were sig-
nificantly correlated \((r = 0.59)\). As with systolic pressures, striking differences between the recorded pressures and average casual pressures were found in some patients whose average casual pressures were similar. The recorded pressures varied from 83 mm. to 125 mm. Hg in patients whose average casual pressure was 120 mm. Hg. Most of the recorded pressures were below the line of identity or were very close to it, indicating that they were lower than the casual pressure. In seven instances, the average recorded pressure was slightly higher than the average casual pressure, but in only one patient was this difference as great as 10 mm. Hg. In contrast, the average recorded pressure was commonly 20 to 35 mm. Hg less than the average casual pressure.

The averages of both the five highest and the five lowest pressures recorded by each patient were highly correlated with the average of all his recorded pressures (table 4 and fig. 5). The same high correlation was found between the single highest pressure, or single lowest pressure, and the average of all pressures recorded by the patient.

The regression of the five highest, the five lowest, and the average values obtained with the portable recorder on the casual pressure values are plotted in figure 8. It is apparent that if the average casual pressure was about 200 mm. Hg systolic, it more closely conformed to the average of the five highest systolic pressures than to the average systolic pressures obtained with the recorder. In contrast, when the average casual pressure was about 160 mm. Hg systolic, it more closely approximated the average systolic pressure recorded with the portable recorder than the average of the mean of the five highest readings. The average of the five lowest systolic pressures was about 10 mm. Hg lower than the casual pressure.

![Figure 7](image)

**Figure 7**

Relationship of average diastolic blood pressure measured with the portable recorder to average "casual" pressure in 62 patients. Each dot represents one subject. The broken line is the line of identity, and the solid line is the line of regression.

### Table 4

Statistical Intercorrelation between Various Blood Pressure Indexes and Average Pressure Obtained with Portable Recorder in 62 Subjects

<table>
<thead>
<tr>
<th>Blood pressure index</th>
<th>Correlation with average recorded pressure</th>
<th>Correlation with average recorded pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>r*</td>
<td>b</td>
</tr>
<tr>
<td>Standard deviation from the mean</td>
<td>0.34</td>
<td>0.08</td>
</tr>
<tr>
<td>Highest single pressures recorded</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Lowest single pressures recorded</td>
<td>0.89</td>
<td></td>
</tr>
<tr>
<td>Average of 5 highest pressures recorded</td>
<td>0.92</td>
<td>1.09</td>
</tr>
<tr>
<td>Average of 5 lowest pressures recorded</td>
<td>0.92</td>
<td>0.80</td>
</tr>
<tr>
<td>Average casual pressure</td>
<td>0.74</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Abbreviations: r, correlation coefficient; b, slope of regression line; A, intercept of regression line.

* Significant values \((p < 0.01)\) are shown in italic type; NS, not significant.
pressures obtained with the recorder was considerably below the average systolic casual pressure, the difference being greater at higher than at lower average casual pressures. The relationships of the diastolic pressures were similar. The difference between the average casual and the average recorded systolic pressures was not simply due to equivalent percentage rises. Thus, with 10-mm. increments in average recorded systolic pressures from 150 to 210 mm. Hg, the difference between the average recorded and average casual pressures was 2, 6, 11, 14, 16, 19, and 21 per cent, or 3, 10, 18, 25, 31, 38, and 45 mm. Hg, respectively.

The three blood pressure indexes indicated by the three regression lines in figure 8 are highly correlated \( r = 0.92 \) both for the correlation between the average and the mean of the five highest systolic pressures and for the correlation between the average and the mean of the five lowest recorded systolic pressures). The comparable correlation coefficients for the diastolic pressures are 0.94 and 0.95, respectively. Knowledge of the average casual pressure in a group of patients therefore permits prediction of the approximate average recorded pressure, as indicated in figure 8. Individual variations (as shown in figs. 6 and 7, but not in fig. 8), however, prevent an accurate prediction in any one patient.

**Discussion**

The data obtained in this study show that it is possible to obtain accurate systolic and diastolic blood pressure readings on hypertensive patients during their usual daily routine, whether sedentary or active. In addition, these pressures give a representative picture of the average blood pressure and its variability throughout the day.

The arterial pressure of everyone changes frequently throughout the day as the cardiac output and the peripheral resistance respond to impulses from the central and autonomic nervous systems, from the adrenal glands, and from other sources that regulate the arterial pressure in man. The variability of the blood pressure reflects a variety of chemical, humoral, psychological, and neural actions, which occur at any given time during the course of the day. The influence of the central nervous system, as it receives and integrates various stimuli and emotions throughout the day, must be of great importance in determining variability. The striking differences between the average casual and the average recorded systolic pressures in individual subjects, as illustrated in figures 6 and 7, pose important questions regarding treatment and prognosis.

In hypertension, complications (such as cardiac enlargement, fundal abnormality, and degree of electrocardiographic change of left
ventricular hypertrophy) are thought to be the consequence of the increase in arterial pressure, yet discrepancies exist between the levels of casual pressure and the vascular complications. To what extent can the differences in prognosis among individual hypertensive patients be explained by the differences in behavior of the casual and recorded pressures?

When the present study was begun, we did not know whether 1, 2, or more days of observations would be required for adaptation and to obtain representative readings. Our data show no significant difference between the pressures recorded on day II and day III, although the readings on day I were significantly higher than those on the subsequent 2 days. For this reason, our current practice is to obtain readings only for a 2-day rather than a 3-day period. It is of interest that no progressive rise in pressure occurred during the day, contrary to the generally held opinion. Although a rise or a fall toward evening was noted in some subjects, the average pressure for the group remained on a plateau after 2 p.m. even on the first day.

The correlation between the average recorded systolic pressure and its variability (standard deviation from the mean) was low but significant; for diastolic pressures, there was no correlation. Variability of the diastolic pressure may be an independent index of blood pressure unrelated to the average diastolic pressure. An alternative possibility is that decreased elasticity of the aorta (due to atherosclerosis and common in patients with hypertension) results in a considerably greater rise in systolic than in diastolic pressure in response to environmental and other stimuli.

In some of the previous studies that considered the variability of the blood pressure, a correlation was found between the level of pressure and its variability; in others, like ours, no correlation with diastolic pressures could be shown. The discrepant results may be attributable to the different methods and inconsistent definitions of variability used in these studies.

The data in figures 6 and 7 show that the higher the casual pressure, the greater the difference between the casual and recorded pressure. In the group of patients with relatively low casual pressure, the average casual pressure obtained in the clinic differed little from the average pressure obtained with the recorder. In the group of patients with high casual pressures, however, the average casual pressure was considerably higher than the average recorded pressure. A still more striking contrast was found when the casual pressure was compared with the average of the five lowest recorded pressures, which gives an indication of how low the patient's pressure falls when he is away from a medical environment (fig. 8). In the group of hypertensive patients with average casual pressures of approximately 150 mm. Hg systolic, the average of the five lowest pressures recorded with the portable machine was about 25 mm. Hg less than the casual level. In the group with average casual pressures of about 200 mm. Hg systolic, however, the average of the five lowest recorded pressures was approximately 50 mm. Hg less than the average casual pressure. This finding seems consistent with Smirk's observation that the "supplemental" pressure (difference between the casual and the basal pressure) is greater when casual pressures are high than when they are low.

The average pressure obtained with the portable recorder may reflect more accurately than casual pressures the net "load" to which the cardiovascular system is subjected, and so may explain more rationally the course of the disease in hypertensive patients. Single casual pressures are apt to reflect temporary rises in pressure resulting from stimuli from the central nervous system due to the presence of the physician, the medical environment, or other personal factors, and therefore may not reliably indicate the net daily "load," because pressures may be lower at other times. (The individual differences between casual and recorded pressures indicate how
difficult it is to evaluate the total daily load from single casual pressures in any one patient.) A consistently increased load may accelerate considerably the development of left ventricular hypertrophy and atherosclerosis, whereas transient loads may be less likely to do so. It is essential to determine the relative importance of the blood pressure "floor," the blood pressure "ceiling," and the average load on the cardiovascular system by means of blood pressure measurements taken during an individual's ordinary daily activities. Such measurements of the behavior of the blood pressure in subjects of all ages during their usual activities should help explain many confusing discrepancies in the clinical consequences of an increased casual blood pressure level.

Further research is required to provide better knowledge of the variability of blood pressure and, especially, the environmental and psychological factors that significantly affect the level of blood pressure. Studies relating the development of vascular complications of hypertension to the levels of blood pressure recorded during usual activity are needed to secure more information about the natural course of the disease and, hopefully, find dependable guides for judging prognosis, indications for treatment, and the effectiveness of treatment.

Summary and Conclusions

Further experiences with a portable semi-automatic blood pressure recorder have confirmed that accurate systolic and diastolic blood pressure readings can be taken with ease by a patient at intervals during his normal activities while he is alone and without his being aware of the recorded levels. Sixty-two hypertensive patients recorded their blood pressure at half-hour intervals throughout the day for 2 or 3 consecutive days, allowing determination of the average, range, and variability of arterial pressure, as well as variations in pressure from day to day and within each day.

The range was only slightly correlated with the subject's average blood pressure. No correlation was found between the variability of diastolic pressures and the average pressure, but the variability of systolic pressures was slightly correlated with the average recorded pressure. The averages of the five highest and the five lowest pressures (both systolic and diastolic) recorded by the individual patient were highly correlated with the average of all his pressures. With a few exceptions, the average pressure obtained with the portable recorder was considerably lower than the average casual pressure taken in the clinic. The higher the average casual pressure, the more closely it approximated the average of the five highest pressures obtained with the portable recorder. Average casual pressures in the lower range of hypertensive systolic levels (150 to 160 mm. Hg), however, approximated the average recorded pressure, not the average of the five highest recorded pressures.

Although a significant correlation was found between the average casual and the average recorded pressures of the group, there were wide departures from the average relationship in individual instances. These differences were often striking, and indicate that one cannot predict with precision the recorded pressures from the casual pressures in individual patients.

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References


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