Home Self-Monitoring of Blood Pressure Is Fully Automated Oscillometric Technique as Good as Conventional Stethoscopic Technique?

George S. Stergiou, Angeliki V. Voutsa, Apostolos D. Achimastos, and Theodore D. Mountokalakis

Home blood pressure (HBP) measurement is becoming increasingly popular as an additional source of information for the practicing physician. Whether HBP measured with a fully automated oscillometric device (oHBP) is more reliable than HBP measured with an aneroid sphygmomanometer and a stethoscope (sHBP) remains unclear. We compared sHBP with oHBP using as a reference method daytime ambulatory blood pressure (ABP), as this is believed to be a better index of an individual’s overall level of pressure.

Forty-six hypertensive patients measuring HBP with aneroid devices were retrained by a standard 30 min protocol that included training in the technique of measurement, checking patients’ devices, and testing patients’ performance in stethoscopic measurement. Patients were randomized to measure for 2 weeks either sHBP using their own calibrated aneroid devices or oHBP using a validated fully automated oscillometric device (Omron HEM-705CP). Then 24 h ABP monitoring was performed (SpaceLabs 90207) and patients crossed over for a second 2 week period by using the alternative HBP measurement technique. Mean sHBP was not different from mean oHBP, and there was a close correlation between them (r = 0.82/0.76 for systolic/diastolic BP, P < .001). Daytime ABP was not different from oHBP or sHBP and was closely related to both of them (oHBP, r = 0.59/0.72 systolic/diastolic BP, P < .001; sHBP, 0.50/0.65, P < .001). Age was significantly related with diastolic ABP-sHBP difference (r = 0.33, P < .05). These results suggest that HBP measured with validated fully automated oscillometric devices is equally reliable in predicting average ABP as that measured with calibrated aneroid sphygmomanometers used by very carefully trained patients. In clinical practice, HBP monitoring by using reliable automated devices is probably more feasible than to achieve a high standard of stethoscopic HBP measuring technique. © 1997 American Journal of Hypertension, Ltd. Am J Hypertens 1997;10:428–433

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Monitoring of blood pressure at home (HBP) is a relatively simple and inexpensive technique that provides a large number of measurements taken in the natural environment of the individual patient. There is evidence that HBP is more reproducible than clinic blood pressure (CBP), is free of the "white coat" reaction and placebo effect, and reflects the overall level of BP more reliably than CBP. It has been suggested that HBP is of clinical value in confirming the diagnosis of hypertension, detecting small treatment-induced BP changes, improving patient compliance, and cutting costs by reducing the frequency of clinic visits. Although experience is still limited and more research is needed, this technique is becoming increasingly popular, and guidelines from the Joint National Committee (JNC V), the American College of Physicians, the International Society of Hypertension, and the World Hypertension League recommend self-measurement of BP in selected cases as an additional source of information to the practicing physician. Recently, detailed guidelines were provided by an Ad Hoc Panel from the American Society of Hypertension.

Although the standard mercury sphygmomanometer remains the most accurate device available for noninvasive measurement of BP, for practical reasons aneroid devices have been preferred for self-monitoring of BP at home and, more recently, fully automated electronic devices have become popular. Aneroid devices are cheaper but require a certain degree of manual dexterity, hearing acuity, and time-consuming training. In contrast, fully automated electronic devices are more simple to use and do not need additional training beyond simple instructions. In addition, some electronic devices can store and print BP data and thereby eliminate observer bias. Since there is no legal obligation for manufacturers to comply with the standards that are available, most electronic devices available on the market for self-measurement of BP have not been validated adequately, or have been shown to be inaccurate with very few exceptions. Whether HBP measured by using accurate fully automated electronic devices is equally reliable or even advantageous compared with standard technique by using an aneroid manometer and a stethoscope is unclear.

The objective of the present study is to compare the value of home blood pressure (HBP) measured by using an aneroid sphygmomanometer and a stethoscope (sHBP) or a validated fully automated oscillometric device (oHBP) in predicting average daytime ambulatory blood pressure (ABP), as this is believed to be a better index of an individual’s overall level of pressure.

**SUBJECTS AND METHODS**

**Patients and Training Method** Patients with essential hypertension who attended the Outpatients Blood Pressure Clinic for at least 2 months, who were untreated or were on stable antihypertensive treatment for at least 4 weeks, and who measured HBP with aneroid sphygmomanometers for at least 6 months before study entry were recruited. Patients were carefully retrained in HBP measurement technique with the aim of teaching skills in a manner consistent with the World Hypertension League recommendations. The training session lasted for an average of 30 min and included the following: (1) detailed instructions for the conditions of measurement and the correct technique (bladder size 23 × 12 cm or 28 × 14 cm in patients with arm circumference > 30 cm, Korotkoff phase V for diastolic BP); (2) a check of all parts of patients’ aneroid devices and accuracy testing of the devices against a mercury column by using a Y-connector at six different levels of pressure (60, 90, 120, 150, 180, and 210 mm Hg) for three successive readings (aneroid manometers with more than 4 mm Hg difference from mercury column were discarded and any malfunctioning parts of devices were replaced and rechecked); (3) a test of patients’ ability to take BP correctly with simultaneous measurements (Y-connected stethoscope) until observer–patient difference was <5 mm Hg on two successive readings; and (4) illustrated written instructions handed to patients. Antihypertensive treatment, if any, was continued unaltered throughout the study period. Exclusion criteria included: repeated diastolic BP > 120 mm Hg or systolic > 220 mm Hg during the study and any change in antihypertensive medication or in treatment with any drugs known to influence BP, 4 weeks before and during the study. All patients gave informed consent for study participation.

**Measurements** Patients were randomly allocated to either a group measuring sHBP for 2 weeks by using their own calibrated aneroid sphygmomanometers and a stethoscope or to a group measuring oHBP with a validated electronic device (Omron HEM-705CP, Omron Corp., Tokyo, Japan). This digital readout oscillometric device, which inflate and deflate the cuff with the push of a button, was selected because previous work has shown that it is reliable and complies with the standards of the Association for the Advancement of Medical Instrumentation (AAMI) and the British Hypertension Society Protocol for the evaluation of automated and semiautomated devices. Six calibrated electronic devices were used (bladder size 23 × 12 cm or 28 × 14 cm where appropriate). At the end of the first 2-week HBP measurement, patients in the two groups switched for a second 2-week period to the alternative HBP measurement technique. Patients were in-
structed to make duplicate morning and evening measurements after 5 min sitting rest and with 1 min between recordings on 3 work days per week for each HBP measurement period (24 recordings per period).

ABP was measured with noninvasive portable oscillometric devices SpaceLabs 90207 (SpaceLabs Inc, Redmond, WA, bladder size 23 × 12 cm or 30 × 14 cm where appropriate), which were applied on a workday between the first and the second HBP measurement period. The recorders were programmed to measure BP at 20 min intervals for 24 h. Participants were instructed to follow their usual daily activities but to stay still with the forearm extended during each reading. Clinic BP was measured in two morning visits at the beginning and the end of the study by three physicians that fulfilled the British Hypertension Society Protocol criteria for observer agreement in BP measurement. Following recommendations by the American Society of Hypertension, triplicate BP measurements were taken at each clinic visit after 5 min sitting rest and with at least 1 min between recordings by using a standard mercury sphygmomanometer (bladder size 15 × 35 cm, Korotkoff phase V for diastolic BP).

Analysis of BP Data Twelve duplicate HBP recordings were averaged to give a single number for each 2-week HBP period per individual. The mean value of the second and third CBP measurements at the beginning and the end of the study was used for analysis. The average of daytime ABP recordings was used for analysis. Daytime period was defined according to individuals’ sleeping hours. BP measurements flagged by the software of the monitors as technically erroneous were excluded, as were measurements with systolic BP < 70 mm Hg or > 260 mm Hg or with diastolic BP < 40 mm Hg or > 150 mm Hg. Early readings taken less than 20 min after the monitor was attached to the patient were also excluded, as these were taken in the clinic. Pearson correlations were used to investigate the association between BP values obtained by different BP measurement techniques. A paired t test was used for the comparison of these BP values, with Bonferroni’s correction for multiple comparisons applied where appropriate. The Bland-Altman approach was also employed in order to investigate the degree of similarity between sHBP and oHBP and to assess which of them gives the more reliable estimate of ABP. Mean discrepancy (bias) between BP measures was calculated together with standard deviation of differences (SDD) and 95% confidence intervals for discrepancy. A probability value \( P < .05 \) was considered statistically significant.

RESULTS

Among 53 consecutive patients recruited, three dropped out after randomization because of reasons unrelated to the study, and four were rejected because they provided an inadequate number of HBP measurements. Data from 46 patients (27 men and 19 women) were analyzed. Mean age was 54.7 ± 11.7 (SD) years, BMI 27.8 ± 3.5 kg/m² and 26 patients (56%) were on antihypertensive drug treatment. Mean duration of clinic attendance before study entry was 6.7 ± 6.3 months (range 2 to 28 months) with 3.6 ± 2.7 clinic visits (range 2 to 15). The average number of trials until two acceptable readings were obtained (less than 5 mm Hg observer–patient difference on simultaneously BP measurements with Y-connected stethoscope) was 2.9 ± 1.0 (range 2 to 5 trials).

A total of 49 ± 5.9 (mean ± SD) readings were obtained during daytime ABP monitoring. A fraction of 11.4% ± 4.7% of readings that satisfied at least one of the editing criteria were considered erroneous and were discarded. In the majority of time points where erroneous readings were obtained, a successful reading was obtained on an automatically repeated measurement 2 min later. Nevertheless, a fraction of 3.7% ± 3.1% of time points were not represented in the daytime ABP profile, as both initial and repeated readings were considered erroneous.

Average CBP, stethoscopic and oscillometric HBP, and mean daytime ABP are presented in Table 1. CBP (mean value of 2 visits) was 138.1 ± 14.3/88.1 ± 9.3 mm Hg (mean ± SD for systolic and diastolic BP, respectively), with no difference between clinic visits. Pearson correlations and description of discrepancies for the Bland-Altman technique between different BP measurement techniques is given in Table 2. A description of discrepancies between sHBP and oHBP is also presented in Figure 1. Mean sHBP (133.7 ± 12.2/83.2 ± 9.9 mm Hg) was not significantly different and was closely related to oHBP. Daytime ABP (132.7 ± 12.3/84.4 ± 10.2 mm Hg) was not significantly different, and was closely related to both sHBP and oHBP (Tables 1 and 2). Terminal digit preference was a common phenomenon with sHBP (32.3 ± 17.7% of measurements with zero terminal digit for sHBP versus 10.5% ± 4.8% for oHBP, \( P < .01 \)). Age was sig-

<table>
<thead>
<tr>
<th>TABLE 1. CLINIC BP, AVERAGE STETHOSCOPIC AND OSCILLOMETRIC HOME BP, AND DAYTIME AMBULATORY BP (MEAN ± SD, mm Hg)</th>
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</thead>
<tbody>
<tr>
<td><strong>Systolic BP</strong></td>
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<tr>
<td>---------------------------</td>
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<tr>
<td>CBP</td>
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<tr>
<td>oHBP</td>
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<tr>
<td>ABP</td>
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<tr>
<td>CBP, clinic BP; sHBP, stethoscopic home BP; oHBP, oscillometric home BP; ABP, daytime ambulatory BP; * P for discrepancy from clinic BP &lt; .05; † P &lt; .01; ‡ P &lt; .001.</td>
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</table>
TABLE 2. PEARSON CORRELATIONS AND DESCRIPTION OF DISCREPANCIES FOR BLAND-ALTMAN TECHNIQUE BETWEEN CLINIC BP, STETHOSCOPIC AND OSCILLOMETRIC HOME BP, AND DAYTIME AMBULATORY BP

<table>
<thead>
<tr>
<th></th>
<th>r</th>
<th>P for Correlation</th>
<th>Mean Difference</th>
<th>SDD</th>
<th>P for Discrepancy</th>
<th>95% Limits of Agreement</th>
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</thead>
<tbody>
<tr>
<td>SBP</td>
<td></td>
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<tr>
<td>CBP v sHBP</td>
<td>0.54</td>
<td>&lt;.001</td>
<td>4.1</td>
<td>12.8</td>
<td>.046</td>
<td>(−21.5, 29.7)</td>
</tr>
<tr>
<td>CBP v oHBP</td>
<td>0.58</td>
<td>&lt;.001</td>
<td>4.8</td>
<td>13.2</td>
<td>.015</td>
<td>(−21.6, 31.2)</td>
</tr>
<tr>
<td>CBP v ABP</td>
<td>0.37</td>
<td>&lt;.05</td>
<td>5.4</td>
<td>15.1</td>
<td>.018</td>
<td>(−24.8, 35.6)</td>
</tr>
<tr>
<td>ABP v sHBP</td>
<td>0.50</td>
<td>&lt;.001</td>
<td>−1.4</td>
<td>12.2</td>
<td>.45</td>
<td>(−25.8, 23.0)</td>
</tr>
<tr>
<td>ABP v oHBP</td>
<td>0.59</td>
<td>&lt;.001</td>
<td>−0.6</td>
<td>12.2</td>
<td>.74</td>
<td>(−25.0, 23.8)</td>
</tr>
<tr>
<td>sHBP v oHBP</td>
<td>0.82</td>
<td>&lt;.001</td>
<td>0.7</td>
<td>8.3</td>
<td>.59</td>
<td>(−15.9, 17.3)</td>
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<tr>
<td>DBP</td>
<td></td>
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<tr>
<td>CBP v sHBP</td>
<td>0.72</td>
<td>&lt;.001</td>
<td>4.7</td>
<td>7.2</td>
<td>.0001</td>
<td>(−9.7, 19.1)</td>
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<tr>
<td>CBP v oHBP</td>
<td>0.66</td>
<td>&lt;.001</td>
<td>5.6</td>
<td>7.6</td>
<td>.0001</td>
<td>(−9.6, 20.8)</td>
</tr>
<tr>
<td>CBP v ABP</td>
<td>0.59</td>
<td>&lt;.001</td>
<td>3.7</td>
<td>8.9</td>
<td>.006</td>
<td>(−14.1, 21.5)</td>
</tr>
<tr>
<td>ABP v sHBP</td>
<td>0.65</td>
<td>&lt;.001</td>
<td>0.9</td>
<td>8.4</td>
<td>.45</td>
<td>(−15.9, 17.7)</td>
</tr>
<tr>
<td>ABP v oHBP</td>
<td>0.72</td>
<td>&lt;.001</td>
<td>1.9</td>
<td>7.3</td>
<td>.08</td>
<td>(−12.7, 16.5)</td>
</tr>
<tr>
<td>sHBP v oHBP</td>
<td>0.76</td>
<td>&lt;.001</td>
<td>1.1</td>
<td>6.6</td>
<td>.28</td>
<td>(−12.1, 14.3)</td>
</tr>
</tbody>
</table>

SDD, standard deviation of differences; CBP, clinic BP; sHBP, stethoscopic home BP; oHBP, oscillometric home BP, ABP, daytime ambulatory BP; r, Pearson correlation coefficient.

significantly related to diastolic ABP−sHBP difference (r = 0.33, P < .05) but not with systolic BP. No relation was observed between age and ABP−oHBP difference. There was no difference in the relation between sHBP or oHBP with ABP in men as compared with women. Finally, no relation was found between the ABP−sHBP or ABP−oHBP difference and the number of trials needed until two acceptable simultaneous readings (less than 5 mm Hg observer−patient difference) were obtained during the training session.

DISCUSSION

In the present study only patients familiar with the clinic setting were included, thus no change in CBP from the beginning to the end of study was observed. Self-measurement of BP taken at home by using conventional stethoscopic technique and calibrated aneroid devices was compared with measurements taken by using a validated fully automated oscillometric device. ABP that is more representative of the true blood pressure over time was used as a reference value. Since 24 h average ABP may be affected from the duration and the quality of nighttime sleep, daytime ABP was used for analysis. The actual daytime period, determined by using individual patients’ diaries, was preferred because there is evidence that arbitrary daytime periods may lead to underestimation of daytime ABP.21

FIGURE 1. Discrepancies for Bland-Altman technique between stethoscopic and oscillometric home BP.
In line with previous studies, we observed that, in hypertensive patients, BP taken in the clinic environment is higher than HBP\textsuperscript{22–24} or average daytime ABP,\textsuperscript{21} whereas HBP is on average the same as daytime ABP\textsuperscript{2,23} and is more closely related to ABP than CBP.\textsuperscript{23} HBP values obtained by using two different measurement techniques (stethoscopic versus oscillometric) were found very close to each other, and there was no difference in their ability to predict average daytime ABP.

It is clearly important that patients be adequately trained in the stethoscopic BP measurement technique.\textsuperscript{6} It has been shown that, in practice, HBP taken by inadequately trained patients offers no advantage over CBP.\textsuperscript{25} Teaching of self-measurement requires commitment and takes time.\textsuperscript{6} Studies have shown wide variation in patients’ ability to record BP accurately,\textsuperscript{26,27} and most patients require additional training beyond the manufacturer’s instructions.\textsuperscript{28} Furthermore, defective machines can lead to a false diagnosis and therefore regular calibration is also essential. It should be emphasized that in the present study, although patients were experienced in measuring HBP with the stethoscopic technique, they were retrained very carefully by following a strict 30 min protocol before study entry, their own aneroid devices were checked and repaired where appropriate, and their ability to record Korotkoff sounds accurately by using their own devices was objectively tested. Thus, a high level of reliability for sHBP was expected.

Fully automated oscillometric devices may be advantageous in patients who do not have the necessary sensory acuity or who are unable to measure BP accurately by using the stethoscopic technique. This might be more pronounced in older patients in whom diastolic oHBP was more reliable than sHBP in the present study. Furthermore, it has been shown that the muscular activity required for cuff inflation results in a transient rise in systolic BP that takes on average 7 sec to return to baseline levels, and therefore may lead to overestimation of systolic BP to varying degrees dependent on the rate of deflation.\textsuperscript{29} Fully automated devices are devoid of this effect. In addition, these devices are simple to use, do not require particular skills, and do not need time-consuming training. Unfortunately, the vast majority of electronic devices have not been validated or have been shown to be inaccurate.\textsuperscript{13–16} In the present study, stethoscopic HBP was compared with oHBP taken by using one of the very few reliable, fully automated oscillometric devices.\textsuperscript{18}

In conclusion, in the present study HBP measured by using a validated, fully automated oscillometric device was equally reliable in predicting average daytime ABP as compared with HBP measured with calibrated aneroid sphygmomanometers used by very carefully trained patients. Although the cost of modern, fully automated electronic devices often exceeds 3- to 4-fold the cost of aneroid devices, a comparative cost analysis should also include the cost of patient training. This issue is not addressed in the present study. In line with previous reports, this study showed that patients are able to learn the stethoscopic technique quite well and rapidly. However, in clinical practice, since patient training resources are not widely available, the use of reliable electronic devices for home monitoring of BP is probably more feasible than to achieve a high standard of stethoscopic HBP measuring technique by carefully trained patients.

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