Home Blood Pressure Monitoring

Steven A. Yarows, MD; Stevo Julius, MD, ScD; Thomas G. Pickering, MD, DPhil

Hypertension is estimated to affect 43 to 56 million adults or 24% to 31% of the US population and is emerging as a major health problem in some countries in the Third World.1-3 Hypertension contributes to all the major atherosclerotic cardiovascular disease outcomes.

Blood pressure (BP) can be monitored at the office (clinic) and at home using conventional or ambulatory BP monitors (ABPMs). Ownership of home BP (HBP) monitors is becoming popular and usually occurs without physician encouragement.4 The world BP monitor sales have grown from $484 million in 1992 to $525 million in 1995 and are projected to grow to $597 million by 2002 (Eric Vennemeyer, written communication, December 10, 1997). Higher sales are likely due to the following factors: marketing and a population that is aging and increasingly obese and health conscious. These factors become more important as underdeveloped countries become similar to industrialized nations.5

In the early 1980s, 7.5% to 17.0% of homes in the areas of Minneapolis–St Paul, Minn, and Hamburg, Germany, had sphygmomanometers, whereas 44% to 66% of individuals with hypertension measured their own BP.5-7 Of the patients recording the BP at home, 50% to 73% bought the monitor without physician advice and were not trained by qualified personnel.

Despite the common use of these devices by patients, the only recommendation about the correct use of HBP monitors is from ad hoc panels of the American Society of Hypertension8 and the Canadian Coalition for High Blood Pressure Prevention and Control.9 Other groups encourage self-measurement of BP; however, they are not specific on the use of the monitors for assessment of therapy.10-14 The British Hypertension Society15 did not mention HBP monitoring in their recommendations for management of essential hypertension. In this article, we review the history of HBP monitoring, types of monitors, how BP is determined, reliability and predictability of HBP monitors, and how HBP monitoring affects outcomes.

HISTORY OF HBP MONITORING

The first BP measuring device was developed by the Italian physician Scipione Riva-Rocci, MD, and brought to the United States by Harvey Cushing, MD, in 1901.16 Brown17 in 1930 was the first to report patient self-measurement of systolic BP for assessment of the effect of drugs. Ayman and Goldshine18 were the first to report in 1940 that HBP was less than office BP (OBP). They suggested that HBP monitoring was useful for (1) instructing the patients about their chronic disease, (2) teaching physicians about the natural course of the disease and about factors that affect the disease, (3) learning the prognosis of the disease, and (4) increasing the precision of determining the effectiveness of treatment.

TYPES OF AND DIFFERENCES IN MONITORS

Several types of BP monitors are available for public use. The classic mercury manometer is not popular in the home and is becoming less popular for office use because of environmental concerns about...
mercury manometers are used with a stethoscope and are usually inexpensive. However, they may be less accurate over time, leading to falsely low readings, and recalibration needs to be performed by the manufacturer.20

Electronic devices may use an auscultatory or oscillometric method of detecting BP. The automated auscultatory method was first developed in the mid-1970s, and the oscillometric method was introduced in 1984.21 The oscillometric method uses the small oscillations in cuff pressure to identify the systolic, mean, and diastolic pressures.21 The mean BP is determined at the peak of the amplitude of the oscillations; the systolic BP, approximately 55% prior to the maximum; and the diastolic BP, approximately 85% after the maximum oscillations, although the exact points are proprietary to each manufacturer (Figure). Generally, there is a high correlation between auscultatory and oscillometric devices and simultaneous physician readings.22 The auscultatory method tends to be influenced by unrelated noise, whereas movement influences the oscillometric method. Terminal digit preference, whereby the last numerical digit is rounded, was a more common feature with the stethoscope or aneroid technique (32.3%) compared with the automated electronic monitor (10.5%).21 The oscillometric technique permits faster measurements and is cheaper to manufacture.20 Oscillatory electronic devices have generally replaced auscultatory devices.

Some electronic machines will inflate, deflate, and record the BP automatically, and others need manual inflation and deflation while the monitor records the BP. The self-inflating automated devices are especially useful for patients with arthritis. Some electronic devices have a printer attached and some will store readings that can be downloaded later. Some newer electronic machines use fuzzy logic, which anticipates the systolic BP to allow less overinflation and deflates in a linear as opposed to the usual stepwise fashion. The expense of the devices tends to be related to the degree of automation.

Consumers generally prefer machines with digital readouts and are purchasing an increasing number of electronic HBP monitors (Eric Vennemeyer, written communication, December 10, 1997).24 Sales of electronic monitors have increased from 57% of the world market in 1992 to 58% in 1995 and are expected to increase to 68% in 2002. US consumers purchased 44% of the world market of digital sphygmomanometers in 1992. Finger BP monitors are not accurate for home use.25-28

Wrist measurement of BP using the oscillometric technique has been studied in more than 600 adults in 6 studies and in children and adolescents in 1 study (unpublished data from Omron Healthcare Inc, Vernon Hills, Ill).20-22 There was generally good agreement compared with the upper arm measurement using auscultatory or oscillometric methods; however, the technique showed high variability in individual cases and the correlation coefficients generally were not as high as those using the upper arm method. The wrist measurements are very dependent on position of the device compared with the heart level. In the standing position with an upper arm cuff, BP is approximately 8 mm Hg higher with the arm positioned by the side rather than at heart level for both systolic and diastolic readings.22-23 The formula for correcting the BP based on arm position is to subtract 2 mm Hg from the reading for every inch (2.54 cm) that the BP cuff is below the horizontal plane of the heart.37 When the wrist manometers are used at the correct measurement level, the measurements are accurate.

Stationary machines are often found in pharmacies for public use. The accuracy may vary considerably between machines. The Vita-Stat automatic, coin-operated BP measurement device (Spacelabs Medical Inc, Redmond, Wash) was found inaccurate for clinical use.38-41 The accuracy of other devices that are currently used in community pharmacies has not been determined. These machines may increase the public perception about hypertension and may be considered only for initial self-screening for hypertension.

IS HBP MONITORING ACCURATE?

The common criticism of HBP monitoring is the uncertainty about whether the data are accurate. The reported accuracy of HBP monitors

**Figure**  
Oscillometric technique compared with the auscultatory technique for measurement of blood pressure (BP). Am indicates auscultatory systolic BP; Ams, auscultatory mean BP; and Ad, auscultatory diastolic BP. Reproduced with permission from Biomedical Instrumentation and Technology.21
The BP inaccuracy may stem from the operator of the device or from the device itself. There are many reasons within each of these categories, some of which are unique to the device (Table 1). Occasional differences of less than 5 mm Hg are rarely clinically important, especially if many measurements are taken. However, consistent differences of 5 mm Hg may result in the false diagnosis of new or uncontrolled hypertension. Unfortunately, the aneroid sphygmomanometers are similarly unreliable and were found to be inaccurate in 80% of the units tested at a university hospital and clinics.42

The industry is regulated by the Food and Drug Administration in the United States, which uses the Association for the Advancement of Medical Instrumentation (AAMI) standards43 for sphygmomanometers. Other countries use the standards of the British Hypertension Society44,45 for BP measurement. The AAMI standards define passing as 95% or greater of the average measurements agreeing within ±10 mm Hg and 85% agreement within ±3 mm Hg. The device is expected to maintain the safety and performance characteristics for 10,000 full cycles. The pressure indicator accuracy is tested in the range of 20 to 250 mm Hg, and the monitor should not differ by more than ±3 mm Hg or 2% of the readings, whichever is greater. The British Hypertension Society standards assess differences between the test and standard sphygmomanometer by grading (eg, “A” for the most accurate and “D” for the least accurate) based on a summation of the percentage of readings with differences of ±5, ±10, and ±15 mm Hg.

Before accuracy standards were developed, HBP monitoring was usually found to be inaccurate; however, some reports confirming accuracy were also found.7,46-48 Once guidelines were published, reports assessed the compliance with the guidelines. Of 23 monitors, 12 (52%) met AAMI standards for diastolic accuracy (39% of devices met both systolic and diastolic standards), whereas 2 of 7 HBP monitors in another study24 failed to meet AAMI criteria. Of the 7, 5 devices (71%) passed an interdevice variability assessment program (conducted by the British Hypertension Society44,45 after 1 month of HBP monitor use twice a day. The following monitors were accurate and complied with the standards of the AAMI43 and/or the British Hypertension Society44,45: Assure models A30 and W20 (Becton Dickinson & Co, Franklin Lakes, NJ); A & D models UA-767 and UA-767PC (A & D Co, Ltd, Tokyo, Japan); Instromedix QD (ALARIS Medical Systems, Inc, San Diego, Calif); Omron models HEM-706, 705CP, 711, 722c, 713c, and 403c (Omron Healthcare Inc); and Terumo model ES-H51 (Terumo Medical Corp, Somerset, NJ) (written communication, Osamu Shirasaki, September 2, 1998; written communication, S. P. Kerestan, July 1998; written communication, Jerry Wang, 1998).23,49-54

Table 1. Errors in Measurement

<table>
<thead>
<tr>
<th>All devices</th>
<th>Incorrect placement of bladder, especially with ceramic microphone devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atrial fibrillation</td>
<td>Incorrect bladder size (should be at least 80% and preferably 100% circumference of arm).</td>
</tr>
<tr>
<td>An oversized cuff is accurate; however, an undersized cuff yields erroneously high readings27</td>
<td>An oversize cuff is accurate; however, an undersized cuff yields erroneously high readings37</td>
</tr>
<tr>
<td>Underinflation of cuff in combination with too rapid deflation leads to an error in systolic measurement</td>
<td>Inadequate pressure gauge (except mercury)</td>
</tr>
<tr>
<td>Inadequate number of readings at 1 or several sittings</td>
<td>Measurement of Korotkoff IV sound</td>
</tr>
<tr>
<td>Inaccurate recording of readings (intentional or otherwise)</td>
<td>Inadequate stethoscope</td>
</tr>
<tr>
<td>Leaking bulbs, valves, and hoses</td>
<td>Stethoscope not over the brachial artery</td>
</tr>
<tr>
<td>Aneroid devices</td>
<td>Terminal digital preference</td>
</tr>
<tr>
<td>Difficult number determination due to visual problems (especially nondigital)</td>
<td>Inadequate hearing acuity</td>
</tr>
<tr>
<td>Inadequate number of readings at 1 or several sittings</td>
<td>Too rapid cuff deflation (especially with bradycardia or atrial fibrillation)</td>
</tr>
<tr>
<td>Inadequate number of readings at 1 or several sittings</td>
<td>Underinflation of cuff in combination with too rapid deflation leads to an error in systolic measurement</td>
</tr>
<tr>
<td>Automatic devices</td>
<td>Transducer not over the brachial artery (auscultatory technique only)</td>
</tr>
</tbody>
</table>

human errors in BP measurement

Although OBP measurement has been the criterion standard, there have been errors with this method in nonresearch settings. The difference between the BP recorded using the correct technique and subsequent office measurements was 6 mm Hg for systolic and 10 mm Hg for diastolic BP.56 Differences between a trained registered nurse and the usual health care providers were 6 mm Hg for systolic and 5 mm Hg for diastolic BP in a family practice center.57 Potentially correctable errors that could be improved by training were estimated to be only 2 mm Hg for systolic and 1 mm Hg for diastolic BP.

measurements of HBP compared with OBP and ABPM

The OBP is the criterion standard for determining hypertension-related cardiovascular morbidity and mor-
tality. It is therefore important to establish if HBP measurements are different than OBP measurements. Table 2 shows the summary of the difference between HBP and OBP. On average, OBP is 8.1/5.6 mm Hg higher than HBP.58-66

Data from ABPM are often reported as 24-hour average and daytime average. The daytime average probably correlates better with the results from HBP monitors since patients usually obtain their BP during the daytime. Table 3 shows that the average difference between the results of daytime ABPM and HBP was −1.7/1.2 mm Hg, which is not clinically important.23,59,60,64,67-70

### Table 2. The Difference Between Blood Pressure (BP) Measured in the Office and at Home*

<table>
<thead>
<tr>
<th>Source, y</th>
<th>No. of Patients</th>
<th>Difference Between Office and Home BP, mm Hg</th>
<th>Systolic/Diastolic BP, SD</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Welin et al,58 1982</td>
<td>31</td>
<td>6.1/0.6</td>
<td>15.4/11.5</td>
<td>23.6/14.1</td>
</tr>
<tr>
<td>Kleinert et al,60 1984</td>
<td>93</td>
<td>10.0/5.0</td>
<td>2/1</td>
<td>2/1</td>
</tr>
<tr>
<td>Bobrie et al,62 1993</td>
<td>46</td>
<td>21.8/11.0</td>
<td>13.3/10.7</td>
<td>16.6/11.9</td>
</tr>
<tr>
<td>de Gaudemaris et al,63 1994</td>
<td>390</td>
<td>8.1/4.8</td>
<td>8/6.5</td>
<td>...</td>
</tr>
<tr>
<td>Sega et al,64 1994</td>
<td>2400</td>
<td>8.0/7.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Mancia et al,65 1995</td>
<td>2400</td>
<td>8.6/7.4</td>
<td>17.0/10.0</td>
<td>16.8/9.8</td>
</tr>
<tr>
<td>Sega et al,66 1997</td>
<td>800</td>
<td>9.4/5.6</td>
<td>18.1/9.5</td>
<td>19.5/10.3</td>
</tr>
<tr>
<td>Battig et al,67 1989</td>
<td>101</td>
<td>8.6/4.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Average</td>
<td>...</td>
<td>8.1/5.6</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

*Ellipses indicate not available.
†Between difference of daytime office BP and home BP.

### Table 3. The Difference Between Daytime Blood Pressure (BP) Measured by an Ambulatory BP Monitor and at Home*

<table>
<thead>
<tr>
<th>Source, y</th>
<th>No. of Patients</th>
<th>Difference Between BP Measured by an Ambulatory BP Monitor and at Home, mm Hg</th>
<th>Systolic/Diastolic BP, SD</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Staessen et al,68 1991</td>
<td>328</td>
<td>4.0/5.0</td>
<td>22.0/16.0</td>
<td>0.72/0.60</td>
</tr>
<tr>
<td>Staessen et al,69 1994</td>
<td>530</td>
<td>−3.0/−1.0</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Stergiou et al,70 1997</td>
<td>Aneroid sphygmomanometer 46</td>
<td>−1.0/1.2</td>
<td>12.2/9.9</td>
<td>12.3/10.2</td>
</tr>
<tr>
<td>Stergiou et al,71 1996</td>
<td>Electronic sphygmomanometer 46</td>
<td>−0.5/1.9</td>
<td>14.4/9.0</td>
<td>12.3/10.2</td>
</tr>
<tr>
<td>Stergiou et al,31 1991</td>
<td>50</td>
<td>−4.2/−0.3</td>
<td>15.0/10.2</td>
<td>13.5/11.2</td>
</tr>
<tr>
<td>Mancia et al,72 1995</td>
<td>2400</td>
<td>3.8/4.0</td>
<td>17.0/10.0</td>
<td>11.0/7.9</td>
</tr>
<tr>
<td>Sega et al,73 1997</td>
<td>800</td>
<td>−10.6/−1.0</td>
<td>18.1/9.5</td>
<td>12.3/7.6</td>
</tr>
<tr>
<td>Bialy et al,74 1988</td>
<td>32</td>
<td>−2.3/−0.5</td>
<td>11.8/7.1</td>
<td>11.7/8.4</td>
</tr>
<tr>
<td>Average</td>
<td>...</td>
<td>−1.7/1.2</td>
<td>...</td>
<td>...</td>
</tr>
</tbody>
</table>

*Ellipses indicate not available.
†Between difference of daytime office BP and home BP.

### Normal Values of HBP

There are 2 methods to define the limits of normality.71 The first method is the distributional criterion, in which subjects whose BP exceeds 2 SDs of the mean are defined as hypertensive, and the second method relates BP to morbidity and mortality outcomes. Mejia et al reported in 1990 the normal values for HBP based on a population-based study of 608 healthy adults aged 18 to 41 years. Using 2 SDs above the mean of the whole population as a cutoff point, the definition of hypertension for men was a BP of 142/92 mm Hg and for women, 131/85 mm Hg.
population was followed up for a mean of 3 years. The authors sought an average HBP that would predict hypertensive BP in future office visits after 3 years with maximum sensitivity and at least 90% specificity. An HBP of 128/83 mm Hg or higher detected sustained hypertension with a sensitivity of 48% and a specificity of 93%.

The PAMELA (Pressione Arteriose Monitorate E Loro Associazioni) study was an Italian population-based study that followed up 2400 patients aged 25 to 64 years. The accepted upper limit of normal for OBP (140/90 mm Hg) using regression lines corresponded to an upper limit of normal of 120/77 mm Hg for both 24-hour average BP and HBP. The PAMELA project also followed up 400 elderly patients (aged 65 to 74 years). Using the regression lines relating HBP to OBP, the upper limit of normal for HBP corresponding to an OBP of 140/90 mm Hg was calculated to be 133/82 mm Hg. A third population-based study reported in a meta-analysis of 17 previous studies that suggested an upper limit of normal of 135/85 mm Hg.

**RELATIONSHIP OF HBP WITH END-ORGAN DAMAGE**

End-diastolic relative wall thickness was measured using M-mode echocardiograms in a comparative study of home, office, and 24-hour ambulatory BP monitoring. The correlation coefficients were higher with home (r = 0.45/0.40; P < .01) than office (r = 0.22/0.07) or 24-hour ambulatory BP (r = 0.26/0.24) readings.

The effect of BP control on the evolution of electrocardiographic evidence of left ventricular hypertrophy was studied in 50 patients during an average 9-year follow-up. The changes in electrocardiographic evidence of hypertrophy were related to the degree of BP control and correlated better with HBP average measurements rather than office measurements.

**IMPROVED PREDICTION OF HYPERTENSION-RELATED MORBIDITY AND MORTALITY WITH THE USE OF HBP MONITORING**

Home BP readings were obtained in a population-based study for 1913 subjects whose mean age was 61 years who underwent a mean follow-up of 5 years in a rural Japanese community. An “excess of relative risk” of 10% was arbitrarily accepted as a serious and substantial risk. Based on this assumption, the home reference value for defining hypertension was calculated to be 137/84 mm Hg or higher, which was equivalent to an excess risk associated with an OBP of 140/90 mm Hg or higher. The relative hazard (RH) of home systolic BP of 137 mm Hg or higher was 1.77 and of diastolic BP of 84 mm Hg or higher, 1.70. These investigators found that a U-shaped curve and a diastolic BP less than 65 mm Hg were associated with an increase of the RH to 1.54.

Despite the differences in methods, the data across studies are reasonably consistent and suggest that the upper limit of normal HBP should be 130/80 to 135/85 mm Hg. This result is comparable to that reported in a meta-analysis of 17 previous studies that suggested an upper limit of normal of 135/85 mm Hg.

**COMPLIANCE WITH THERAPY USING HBP MONITORING**

The reports in the literature are mixed regarding improvement in BP control using HBP monitoring. The reports in the literature are also mixed regarding improvement in BP control using HBP monitoring. Home BP monitoring was shown to lower BP after 6 months to 1 year of use in studies of patients with mild hypertension and patients with difficult to control hypertension. Of patients in one study, 96% thought that measuring their BP at home was “worthwhile” because of the reassurance that their BP was controlled.
however, the general trend suggests a benefit.\textsuperscript{76,83-87}

**COST-EFFECTIVENESS**

There are costs in measuring BP using office visits with or without the physician present. The yearly ambulatory care cost of hypertension treatment per patient at Veterans Affairs hypertension clinics was estimated as $647 in 1980 dollars.\textsuperscript{88} Forty-nine percent of this cost was for clinic visits. We estimated that the total direct cost in Ann Arbor, Mich, for simply measuring BP in an office, without a physician present, is approximately $5.26. Patients also incur direct and indirect costs.

In a study by Soghikan et al.,\textsuperscript{78} there were 1.2 (95% CI, −1.7 to −0.8) fewer physician visits over a year in a home-monitored group compared with the group that received usual care. The mean cost of hypertension care per patient in the home-monitored group was $117, which is 6% less than the group that received usual care. Although this difference was not significant ($P = .44$), out-of-pocket costs for transportation and lost wages were not calculated.

**CONCLUSIONS**

Home BP monitoring has become accurate since standards were developed. The results of monitoring are reproducible, with differences between models less than the differences due to human variation in the auscultation of BP. Home measurements result in lower BP readings than office measurements, with normal values similar to daytime ABPM. An OBP of 140/90 mm Hg is approximately equivalent to an HBP of 130/84 mm Hg. Although several studies indicate that HBP better predicts left ventricular hypertrophy and mortality than OBP, further research is needed. Additional studies are also warranted to determine if HBP monitoring improves BP control and compliance and is cost-effective, although there have been studies showing benefits in each of these areas. It may be time to transfer HBP monitoring from a consumer market to a physician-endorsed activity, with appropriate third-party reimbursement for and physician review of the monitors.

Accepted for publication September 9, 1999.

Reprints: Steven A. Yarows, MD, Division of Hypertension, University of Michigan Health System, 128 Van Buren, Chelsea, MI 48118 (e-mail: syarows@umich.edu).

**REFERENCES**


12. 1986 Guidelines for the treatment of mild hyper-
thension: memorandum from a WHO/ISH meet-
13. The 1988 Report of the Joint National Commit-


