Multiple Clinic and Home Blood Pressure Measurements Versus Ambulatory Blood Pressure Monitoring

Antti Jula, Pauli Puukka, Hannu Karanko

Abstract—To compare multiple clinic and home blood pressure (BP) measurements and ambulatory BP monitoring in the clinical evaluation of hypertension, we studied 239 middle-aged pharmacologically untreated hypertensive men and women who were referred to the study from the primary healthcare provider. Ambulatory BP monitoring was successfully completed for 233 patients. Clinic BP was measured by a trained nurse with a mercury sphygmomanometer and averaged over 4 duplicate measures. Self-recorded home BP was measured with a semiautomatic oscillometric device twice every morning and twice every evening on 7 consecutive days. Ambulatory BP was recorded with an auscultatory device. Two-dimensionally controlled M-mode echocardiography was successfully performed on 232 patients. Twenty-four-hour urinary albumin was determined by nephelometry. Clinic BP was 144.5/94.5 mm Hg, home BP (the mean of 14 self-recorded measures) was 138.9/92.9 mm Hg, home morning BP (the mean of the first 4 duplicate morning measures) was 137.1/92.4 mm Hg, daytime ambulatory BP was 148.3/91.9 mm Hg, nighttime ambulatory BP was 125.5/76.6 mm Hg, and 24-hour ambulatory BP was 141.7/87.2 mm Hg. Pearson correlation coefficients of clinic, home, home morning, and daytime ambulatory BPs to albuminuria and to the characteristics of the left ventricle were nearly equal. In multivariate regression analyses, 36% (P<0.0001) of the cross-sectional variation in left ventricular mass index was attributed to gender and home morning systolic BP in models that originally included age, gender, and clinic, self-measured home morning, and ambulatory daytime, nighttime, and 24-hour systolic and diastolic BPs. We concluded that carefully controlled nonphysician-measured clinic and self-measured home BPs, when averaged over 4 duplicate measurements, are as reliable as ambulatory BP monitoring in the clinical evaluation of untreated hypertension. (Hypertension. 1999;34:261-266.)

Key Words: blood pressure □ blood pressure monitoring, ambulatory □ blood pressure monitoring □ ventricular function □ albuminuria

The definition of an individual’s blood pressure (BP) level has long been based on clinic BP recorded by physicians or nurses. However, clinic BP may not necessarily represent an individual’s usual BP level. Several studies suggest that clinic BP is higher than self-measured or ambulatory BPs.1–7 BP measured by a physician tends to be higher than BP measured by a nonphysician.8–11 Compared with clinic BP, ambulatory BP has in several studies shown to be a better indicator of left ventricular hypertrophy.12 Classification of a patient’s hypertensive status by conventional measurement techniques may thus lead to overdiagnosis and overtreatment of hypertension. Unfortunately, most of the studies that compare clinic BP measurements with ambulatory BP monitoring do not describe the clinic BP measurement technique, the type of observer (physician or nonphysician), the number of measurement sessions, and the number of measurements per session.

Self-measured BP has usually been higher than daytime ambulatory BP.1–7 To the best of our knowledge, it is not known whether ambulatory BP is superior to self-measured BP as an indicator of left ventricular hypertrophy and microalbuminuria.

The purpose of our study was to compare multiple, carefully controlled clinic and self-measured home BP measurements with ambulatory BP monitoring in the clinical evaluation of untreated hypertension. More precisely, we wanted to examine and compare levels and relations of ambulatory, clinic, and self-measured home BPs as well as their relationships to albuminuria and echocardiographic measures of the left ventricle.

Methods

Subjects

General practitioners and internists within the primary and occupational health services in the city of Turku and 3 neighboring municipalities (a population of ~200,000 inhabitants) in southwestern Finland were requested to refer newly diagnosed, moderately to severely hypertensive but pharmacologically untreated men and women, 35 to 54 years old, to the study. The inclusion criteria were

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Measurements

Recruitment BP was defined as the mean of the last 2 measurements made by the primary healthcare staff. Clinic BP was measured by a trained nurse. It was recorded between 8 AM and 10 AM with the patient in the sitting position with a mercury sphygmomanometer. A cuff with a bladder width of 15 cm was used. Patients were requested to refrain from heavy exercise in the morning and to avoid coffee, tea, and smoking for at least 1 hour before the measurement. BP was measured after the patient had rested for 15 minutes. The last 5 minutes of rest were spent in the measurement room with the cuff around the right upper arm. Cuff inflation pressure was then determined by palpating the disappearance and appearance of the radial pulse. BP was recorded twice, with approximately a 2-minute interval. Duplicate measurements were done in 4 separate sessions within 3 weeks. Clinic BP was determined as the mean of the 4 duplicate BP measures.

Home BP was self-measured with a semiautomated oscillometric device (Omron HEM 705C). The device meets the criteria for accuracy according to the revised protocol of the British Hypertension Society and the revised standards of the Association for the Advancement of Medical Instrumentation. A cuff with a bladder width of 13 cm was used for subjects with an arm circumference of ≤35 cm, and a cuff with a bladder width of 15 cm was used for subjects with an arm circumference >35 cm. Patients received written instructions and individual guidance on how to measure BP correctly. Preparations for self-measured home BP were the same as for clinic BP. Seated BP was measured twice, approximately at a 2-minute interval every morning between 6 AM and 9 AM and 9 AM and every evening between 6 PM and 9 PM on 7 consecutive days. Home BP was determined as the mean of 14 duplicate measures.

Ambulatory BP was recorded with an auscultatory device (Sun-tech, Accutracker II) according to the guidelines of the Berlin Consensus Document. A cuff with the same bladder width as that used in home measurements was used. Correct position of the microphone was controlled when the recorder was fitted by use of a microphone. Ambulatory BP was recorded during daytime (6 AM to 11 PM) at 15-minute intervals and during nighttime (11 PM to 6 AM) at 30-minute intervals. Twenty-four–hour, daytime, nighttime, and awake BP were recorded from hourly means. Only full hours of wakefulness and sleep were included in the calculation of true awake and true asleep BPs. Measurements were performed according to the recommendations of the American Society of Echocardiography (ASE). The leading edge to leading edge convention was used. Left ventricular echocagrams were measured at or immediately below the tips of mitral leaflets and averaged over ≥3 heart cycles. ASE cube left ventricular mass (g) was calculated as 1.05×[(interventricular septal thickness in diastole+left ventricular internal dimension in diastole+posterior wall thickness in diastole)−left ventricular internal dimension in diastole]. Corrected left ventricular mass (g) was calculated with the equation developed by Devereux and coworkers: 0.80×(ASE cube left ventricular mass)+0.6.

Twenty-four–hour urine was collected for albumin measurements. Albumin was determined by nephelometry (Orion Diagnostica 667560), with a measurement range of 0.5 to 16 mg/dL. The day-to-day variation in albumin measurements was 6.2% at the level of 3.4 mg/dL of albumin, and the intra-assay variations were 5.7% at the level of 4.9 mg/dL of albumin and 3.9% at the level of 9.4 mg/dL of albumin.

### Results

The subjects in this study were 136 men and 97 women (Table 1). During the last 12 months before the study, their phase-array transducer. All echocardiographic studies were performed by the same experienced physician (H.K.), who also analyzed the tracings blinded to the BP readings of individual patients. Measurements were performed according to the recommendations of the American Society of Echocardiography (ASE). The leading edge to leading edge convention was used. Left ventricular echocagrams were measured at or immediately below the tips of mitral leaflets and averaged over ≥3 heart cycles. ASE cube left ventricular mass (g) was calculated as 1.05×[(interventricular septal thickness in diastole+left ventricular internal dimension in diastole+posterior wall thickness in diastole)−left ventricular internal dimension in diastole]. Corrected left ventricular mass (g) was calculated with the equation developed by Devereux and coworkers: 0.80×(ASE cube left ventricular mass)+0.6.

### Statistical Analyses

Statistical values are given as mean±SD. Before statistical analyses, the skewed distribution of albuminuria data was corrected logarithmically. Differences between 2 BP variables were tested by paired t test. Repeated-measures ANOVA was used for comparisons of >2 BP variables. If significant, the pairwise comparisons were made with application of the rule for multiple comparisons recommended by Bonferroni. Bland-Altman plots were used to show individual variations in differences of self-measured home and clinic BPs and of clinic and daytime ambulatory BPs on different BP levels. Associations between clinic BPs, self-measured home BPs, ambulatory BPs, albuminuria, and echocardiographic measures of the left ventricle were tested by calculating bivariate Pearson’s product moment correlation coefficients. To determine independent BP correlates of left ventricular mass index, stepwise multivariate regression analyses with age, gender (1 man; 2 women), and clinic, self-measured home, and ambulatory daytime, nighttime, and 24-hour BPs were made.

#### Table 1. Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men/Women</th>
<th>136/97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td></td>
<td>46.0±4.9 (35.0–54.0)</td>
</tr>
<tr>
<td>Body weight, kg</td>
<td></td>
<td>82.4±15.8 (52.0–140.2)</td>
</tr>
<tr>
<td>Body mass index, kg/m²</td>
<td></td>
<td>27.7±4.2 (19.1–46.3)</td>
</tr>
<tr>
<td>Recruitment SBP, mm Hg</td>
<td></td>
<td>161.6±13.3 (132.5–205.0)</td>
</tr>
<tr>
<td>Recruitment DBP, mm Hg</td>
<td></td>
<td>105.5±5.6 (87.0–122.5)</td>
</tr>
<tr>
<td>Left ventricular mass, g</td>
<td></td>
<td>219±63 (89.3–440.4)</td>
</tr>
<tr>
<td>Left ventricular mass index, g/m²</td>
<td></td>
<td>111±25 (57.6–179.0)</td>
</tr>
<tr>
<td>Urinary albumin, mg/24 h</td>
<td></td>
<td>25.7±39.3 (5.0–434.0)</td>
</tr>
<tr>
<td>Socioeconomic class, %</td>
<td>Manual workers: 41</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lower-level employees: 42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Upper-level employees: 11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Others: 6</td>
<td></td>
</tr>
<tr>
<td>Values are mean±SD, with ranges in parentheses. SBP indicates systolic blood pressure; and DBP, diastolic blood pressure.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
BPs had been recorded on average 9 (range, 1 to 33) times within the primary healthcare system. On the basis of patient history and fasting blood glucose, non-insulin-dependent diabetes was diagnosed in 7 patients and glucose intolerance in 12 patients. Seventeen percent of all subjects (8% of patients with diabetes and 13% of patients with glucose intolerance) had microalbuminuria (daily urinary excretion of 30 to 300 mg). Two patients, 1 with glucose intolerance, had microalbuminuria (daily urinary excretion of 30 to 300 mg).

Comparisons Within Clinic, Self-Measured Home, and Ambulatory BPs

The BP variation between the 4 clinic measurement sessions (Figure 1) was small but statistically significant ($P<0.001$, ANOVA). When compared with the first clinic session, mean diastolic BP of the second session was 1.6±6.6 mm Hg higher ($P<0.01$; 5th to 95th percentiles, −9 to +14 mm Hg), mean diastolic BP of the fourth session was 1.7±7.6 mm Hg lower ($P<0.01$; 5th to 95th percentiles, −11 to +15 mm Hg), and mean systolic BP of the fourth session was 3.2±11.5 mm Hg lower ($P<0.001$; 5th to 95th percentiles, −16 to +22 mm Hg).

Throughout clinic sessions, the first systolic BP readings were higher than the second (Figure 1). The mean differences between all first and second BP readings (first readings minus second readings) were 0.9±2.7 mm Hg ($P<0.001$; 5th to 95th percentiles, −3 to +6 mm Hg) for systolic BP and 0.1±1.8 mm Hg ($P=NS$; 5th to 95th percentiles, −2.5 to +3.0 mm Hg) for diastolic BP.

Self-measured home BPs and heart rates are shown in Table 2. When compared with the morning BP, home evening systolic BP was 3.7±6.6 mm Hg higher ($P<0.001$; 5th to 95th percentiles, −7.6 to +15.5 mm Hg) and home evening diastolic BP was 1.0±4.6 mm Hg higher ($P<0.01$; 5th to 95th percentiles, −7.1 to +8.5 mm Hg). The mean differences between all first and second readings of the 14 home sessions (first readings minus second readings) were 2.5±2.6 mm Hg ($P<0.001$; 5th to 95th percentiles, −1.7 to +6.4 mm Hg) for systolic BP and 1.3±1.6 mm Hg ($P<0.001$; 5th to 95th percentiles, −1.1 to +3.9 mm Hg) for diastolic BP.

Ambulatory awake BP was 1.3±1.5/0.9±1.0 mm Hg higher ($P<0.001$ for systolic and diastolic BPs; 5th to 95th percentiles, −0.3 to +3.7/−0.2 to +2.8 mm Hg) than ambulatory daytime BP, and ambulatory asleep BP was 1.4±3.0/0.4±1.4 mm Hg lower ($P<0.001$, ANOVA) than ambulatory awake BP.

The overall differences between clinic, home, and ambulatory daytime BP values were highly significant ($P<0.001$ for systolic and diastolic BP; 5th to 95th percentiles; 5th to 95th percentiles, −6.6 to 9.9 mm Hg, respectively ($P<0.001$), and ambulatory daytime and awake diastolic BPs were 2.7±6.8 and 1.7±6.9 mm Hg lower, respectively ($P<0.001$) (Table 2, Figure 2).

The differences between self-measured home and clinic BPs and between ambulatory and clinic BPs were normally distributed, with 95% to 98% of the individual differences lying within the range of mean difference ±2 SDs (Figure 2).

Clinic BP correlated significantly ($P<0.001$) with systolic/diastolic ambulatory daytime ($r=0.73/0.59$), nighttime ($r=0.65/0.55$), 24-hour ($r=0.73/0.62$), and self-measured home ($r=0.77/0.67$) BPs. Self-measured home BP correlated significantly ($P<0.001$) with ambulatory daytime ($r=0.78/0.70$), nighttime ($r=0.68/0.64$), and 24-hour ($r=0.78/0.73$) BPs.

Relationships of BPs to the Left Ventricle and Albuminuria

The correlations of clinic and self-measured home BPs to left ventricular mass index and 24-hour urinary albumin increased with increasing number of measurement sessions (data not shown) and reached with 4 measurement sessions the correlations observed for ambulatory BP (Table 3). Left ventricular mass index correlated slightly more strongly with self-measured home morning than evening systolic/diastolic BPs ($r=0.46/0.43$, $P<0.001$ and $r=0.41/0.37$, $P<0.001$ for

![Figure 1. BP and heart rate readings at the 4 clinic measurement sessions. BPs (●) and heart rates (○) are given as mean±SD values.](https://hyper.ahajournals.org/)

![Figure 2. The differences between self-measured home and clinic BPs and between ambulatory and clinic BPs were normally distributed, with 95% to 98% of the individual differences lying within the range of mean difference ±2 SDs.](https://hyper.ahajournals.org/)
home morning and evening BPs averaged over the first 4
duplicate morning and evening measures, respectively).

In stepwise multivariate regression analyses, the variation
of left ventricular mass index was significantly explained by
gender and self-measured home systolic BP in models that
originally included age, gender, and clinic, self-measured

### TABLE 3. Univariate Correlations (Pearson’s r) Between Clinic, Home, and Ambulatory BPs, Characteristics of the Left Ventricle, and Albuminuria

<table>
<thead>
<tr>
<th>BP</th>
<th>LVM</th>
<th>LVMi</th>
<th>IVST</th>
<th>PWT</th>
<th>LUA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systolic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic</td>
<td>0.38†</td>
<td>0.40†</td>
<td>0.35†</td>
<td>0.40†</td>
<td>0.34†</td>
</tr>
<tr>
<td>Home</td>
<td>0.45†</td>
<td>0.47†</td>
<td>0.41†</td>
<td>0.44†</td>
<td>0.32†</td>
</tr>
<tr>
<td>Home morning 1–4*</td>
<td>0.45†</td>
<td>0.46†</td>
<td>0.41†</td>
<td>0.45†</td>
<td>0.31†</td>
</tr>
<tr>
<td>Ambulatory daytime</td>
<td>0.42†</td>
<td>0.46†</td>
<td>0.37†</td>
<td>0.43†</td>
<td>0.33†</td>
</tr>
<tr>
<td>Ambulatory awake</td>
<td>0.41†</td>
<td>0.45†</td>
<td>0.37†</td>
<td>0.43†</td>
<td>0.32†</td>
</tr>
<tr>
<td>Ambulatory nighttime</td>
<td>0.31†</td>
<td>0.35†</td>
<td>0.27†</td>
<td>0.32†</td>
<td>0.25†</td>
</tr>
<tr>
<td>Ambulatory asleep</td>
<td>0.32†</td>
<td>0.35†</td>
<td>0.28†</td>
<td>0.33†</td>
<td>0.26†</td>
</tr>
<tr>
<td>Ambulatory 24-hour</td>
<td>0.40†</td>
<td>0.44†</td>
<td>0.35†</td>
<td>0.41†</td>
<td>0.32†</td>
</tr>
<tr>
<td><strong>Diastolic</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clinic</td>
<td>0.43†</td>
<td>0.37†</td>
<td>0.40†</td>
<td>0.41†</td>
<td>0.25†</td>
</tr>
<tr>
<td>Home</td>
<td>0.44†</td>
<td>0.44†</td>
<td>0.42†</td>
<td>0.43†</td>
<td>0.28†</td>
</tr>
<tr>
<td>Home morning 1–4*</td>
<td>0.44†</td>
<td>0.43†</td>
<td>0.41†</td>
<td>0.43†</td>
<td>0.29†</td>
</tr>
<tr>
<td>Ambulatory daytime</td>
<td>0.35†</td>
<td>0.37†</td>
<td>0.29†</td>
<td>0.35†</td>
<td>0.24†</td>
</tr>
<tr>
<td>Ambulatory awake</td>
<td>0.32†</td>
<td>0.35†</td>
<td>0.28†</td>
<td>0.34†</td>
<td>0.21†</td>
</tr>
<tr>
<td>Ambulatory nighttime</td>
<td>0.30†</td>
<td>0.32†</td>
<td>0.23†</td>
<td>0.30†</td>
<td>0.16§</td>
</tr>
<tr>
<td>Ambulatory asleep</td>
<td>0.31†</td>
<td>0.32†</td>
<td>0.23†</td>
<td>0.30†</td>
<td>0.17§</td>
</tr>
<tr>
<td>Ambulatory 24-hour</td>
<td>0.35†</td>
<td>0.37†</td>
<td>0.29†</td>
<td>0.36†</td>
<td>0.23†</td>
</tr>
</tbody>
</table>

LVM indicates left ventricular mass; LVMi, left ventricular mass indexed by body surface area; IVST, interventricular septal thickness at end diastole; PWT, posterior wall thickness at end diastole; and LUA, logarithmic transformation of urinary albumin (mg/24 h).

*The mean of the first 4 duplicate home morning self-measures.
†P < 0.001, ‡P < 0.01, §P < 0.05.

home, and ambulatory daytime, nighttime, and 24-hour sys-
tolic and diastolic BPs; by gender and self-measured home
diastolic BP in models with diastolic BPs; and by gender and
self-measured mean arterial pressure in models in which
systolic and diastolic BPs were substituted with mean arterial
pressures (Table 4). The findings were essentially the same in
models in which self-measured home BPs averaged over all
morning and evening duplicate measures of 7 consecutive
days were substituted with home morning BPs averaged over
the duplicate morning measures of the first 4 days. For
example, gender and self-measured home morning systolic
BP explained 36% (P < 0.001) of the cross-sectional varia-
tion in left ventricular mass index in models originally
including age, gender, and clinic, self-measured home morn-
ing, and ambulatory daytime, nighttime, and 24-hour systolic
and diastolic BPs.

**Discussion**

The present study showed that nonphysician-measured clinic
and self-measured home BPs, when averaged over 4 carefully
controlled duplicate measures, indicate albuminuria and left
ventricular hypertrophy of middle-aged untreated hyperten-
sive subjects at least equally to ambulatory BP. Several
studies have examined associations between left ventricular
hypertrophy and BP. The correlations with ambulatory BP
have usually been found to be stronger than with clinic BP.12

However, the findings are less consistent in studies with a
large number of patients18 and in studies based on multiple
clinic BP measurements.19 When compared with clinic and
ambulatory BPs, self-measured home systolic and diastolic
BPs were in our study the best indicators of left ventricular
hypertrophy. As much as 36% of the cross-sectional variation
in left ventricular mass index in models originally
including age, gender, and clinic, self-measured home morn-
ing, and ambulatory daytime, nighttime, and 24-hour systolic
and diastolic BPs.
Another important finding was that differences between clinic and ambulatory BP values and between clinic and self-measured home BP values were smaller than usually reported. Ambulatory daytime systolic BP was even slightly higher than clinic systolic BP. Our data are consistent with those of Pearce and colleagues, who made population-derived comparisons between ambulatory and carefully controlled multiple clinic BPs. The correlations between clinic and ambulatory BPs were relatively high and in agreement with studies based on a large number of patients or on multiple clinic BP measurements. In contrast to earlier studies, BP decreased only slightly with increasing number of clinic measurement sessions. Within measurement sessions, BP differences between the first and second readings were smaller than previously reported.

Various factors may explain why clinic BP appeared lower and its variation smaller than expected. First, a large cuff with a bladder width of 15 cm was used in the clinic BP measurements. Compared with self-measured home and ambulatory BP, clinic BP would have been, on average, 3/2 mm Hg higher if it had been measured with cuffs with the same bladder widths as used in home measurements and ambulatory monitoring. Second, the clinic BP was measured 3 times per session. The first measurement to determine the cuff inflation pressure may have had a habituating effect before the 2 ordinary readings. Third, the clinic BP was measured with careful preliminary preparations and standardized measurement techniques. Fourth, an alerting reaction measured with careful preliminary preparations and standardization of the urban population are highly compliant and trainable to measure BP reliably. The correlations between self-measured and clinic and between self-measured and ambulatory BPs were of the same size as seen between clinic and ambulatory BPs. Self-measured home systolic BP was 10 mm Hg lower than ambulatory daytime systolic and 6 mm Hg lower than clinic systolic BP. The differences between clinic, self-measured, and ambulatory daytime diastolic BP values were minor. We found that self-measured home morning BP was, on average, 3.7/1.0 mm Hg lower than self-measured evening BP. However, compared with home evening BP, home morning BP was a slightly better indicator of left ventricular hypertrophy.

In agreement with previous findings, awake BP values were slightly higher and asleep BP values were slightly lower than corresponding arbitrary daytime and nighttime BP values. The correlations of daytime and nighttime BPs with characteristics of left ventricular hypertrophy and with albuminuria were as high as those observed for true awake and asleep BPs. Our findings indicate that normal and reference values for true awake and asleep BPs and for daytime and nighttime BPs differ slightly. Both methods are equally reliable in the determination of the severity of hypertension.

To conclude, nonphysician-measured clinic and self-measured home BPs, averaged over 4 carefully controlled duplicate measures, indicate albuminuria and left ventricular hypertrophy of untreated middle-aged hypertensives equally as well as ambulatory BP. Differences between clinic, home, and ambulatory BP values are quite small and mainly reflect differences in measurement techniques and activities during measurements. Reference values for carefully controlled clinic, self-measured home, and ambulatory BPs are needed.

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References

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