Automated Office Blood Pressure and 24-h Ambulatory Measurements are Equally Associated With Left Ventricular Mass Index

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BACKGROUND
To determine whether automated office blood pressure (AOBP) readings are associated with left ventricular mass (LVM) index as closely as those of 24-h ambulatory blood pressure (ABP) and also to confirm that the values of the two methods are comparable in the appraisal of blood pressure in a European population referred for suspected hypertension.

METHODS
In a sample of 90 individuals with office hypertension, we compared AOBP to awake systolic ABP measurements (ABPM) values and their associations with LVM indices, expressed as LVM divided by body surface area (LVM_BSA) and by height^2.7 (LVM_H^2).

RESULTS
Mean awake systolic ABP was 136 ± 16 mm Hg and mean systolic AOBP was 140 ± 15 mm Hg (P < 0.002). Mean awake diastolic ABP was 87 ± 11 mm Hg and mean diastolic AOBP was 88 ± 12 mm Hg (P = 0.08). AOBP readings were as closely associated with LVM_BSA (r = 0.37) as were those of awake systolic blood pressure (SBP) (r = 0.37). The correlation between LVM_H and both mean awake systolic ABP and mean systolic AOBP was r = 0.37 (P < 0.001) and r = 0.34 (P = 0.001), respectively.

CONCLUSIONS
High-quality AOBP readings and ABP measurements correlate equally well with LVM indices, further supporting the use of AOBP in the clinical setting. Moreover, readings from both techniques are comparable in the assessment of blood pressure.

Keywords: ambulatory blood pressure; automated office blood pressure; blood pressure; hypertension; left ventricular mass index

Traditionally, the prognostic value of hypertension as an independent risk factor for cardiovascular disease was based on auscultatory readings taken in an office setting.¹,² However, ambulatory blood pressure measurements (ABPM) have since been shown by some studies to be a superior predictor.³,⁴ Consequently, ABPM appears to be a more reliable method, were it not for the high cost which does not allow its widespread use among all subjects presenting with office hypertension. A recent study by Myers et al.⁵ showed that automated office blood pressure (AOBP) readings and 24-h ABPM did not differ. The authors further concluded that the automated blood pressure (BP) device virtually eliminated the white-coat response associated with office BP (OBP) readings. Consequently, careful AOBP measurements of a patient left alone in an examination room could reduce the need for 24-h ABPM. Myers⁶ suggested that the predictive value of AOBP could be enhanced by determining a cutoff point rendering it comparable to that of ABPM and thus proposed an algorithm based on the American Heart Association’s classification for daytime ambulatory BP (ABP) readings. Although AOBP and awake ABP have been found to be equivalent, the impact of AOBP on left ventricular mass (LVM) index has not been explored.

In this regard, we sought to evaluate whether AOBP measurements are associated with LVM index in a sample of European subjects referred for suspected arterial hypertension, and whether this association is comparable to that of ABPM. In addition, we examined the agreement between AOBP and ABPM measurements.

METHODS
Study participants. We evaluated all patients referred for suspected hypertension by their family physicians to the 3rd Department of Internal Medicine at “Evangelismos” General Hospital in Athens (Athens, Greece). Only subjects who had never taken or who had not received antihypertensive medication for at least the previous 6 months were considered for inclusion in the study. The inclusion criterion was office hypertension. Hypertension was defined as an average OBP reading of systolic BP (SBP) ≥140 mm Hg or diastolic BP (DBP) ≥90 mm Hg. The exclusion criteria were: previous diagnosis of heart failure, renal disease, diabetes mellitus, or other diseases that could affect BP measurements or LVM index.
≥90 mm Hg (see Study Procedures, BP Measurements section for the protocol in detail).

Exclusion criteria were: secondary hypertension, arrhythmia, history of heart failure, stroke, coronary artery disease, renal insufficiency with serum creatinine >2 mg/dl, mental disorders, and severe noncardiovascular disease, such as cancer or liver cirrhosis, or chronic inflammatory disease. Asymptomatic patients with a low left ventricular (LV) ejection fraction (<50%), regional wall abnormalities or more than a moderate degree of valvular heart disease, based on quantitative Doppler methods, were also excluded, as were patients working night shifts. At baseline, all eligible subjects underwent a medical interview, anthropometric measurements, blood examinations, and echocardiography. Additional risk factors for cardiovascular disease were recorded for each individual, including diabetes mellitus (≥126 mg/dl of fasting blood glucose or the use of antidiabetic medication) and history of smoking.

Written informed consent was obtained from all patients and the study was approved by the scientific board of the hospital.

Study procedures
BP measurements. Three types of reading were obtained:

(i) OBP
(ii) 24-h ABPM
(iii) AOBP

After subjects had remained seated for 5 min OBP was measured by a digital oscillometric BP electronic device (Microlife WatchBP Office, Microlife AG, Widnau, Switzerland) with a medium-large inflatable bladder, 22 × 42 cm and calculated as the mean of three consecutive morning readings, with at least 1 min intervals between recordings, taken between 8:30 and 10:30 at two separate visits. Subjects were asked to refrain from speaking during measurements and a doctor from the study team was present throughout the readings.

Subjects were subsequently monitored by ABP and AOBP techniques over 2 consecutive days.7,8 Day 1 was a routine working day during which the patient was fitted with a 24-h ABP device using a validated electronic Microlife WatchBP 03® bladder size 22 × 32 or 32 × 42 cm where appropriate. The device was programmed to measure at 15-min intervals during the day (0:00 to 23:00) and at 30-min intervals during the night (23:00 to 06:00). Patients were instructed to immobilize their arm at the time of measurement and to keep a diary of daily activities and sleep time. ABP readings of SBP <70 mm Hg or >260 mm Hg and/or DBP <40 mm Hg or >150 mm Hg were disregarded. Accepted levels of normality for ABP measurement in adults during daytime (awake) are 135 mm Hg systolic and 85 mm Hg diastolic; nighttime (sleep) systolic and diastolic values are 120 and 70 mm Hg, respectively.10 Awake SBP and DBP levels were defined based on the participants’ diary reports of their waking and sleeping times.

The following day, the ABPM device was removed and the patient was measured with a Microlife WatchBP Office device,11 inflatable bladder size 12 × 23 or 14 × 30 as appropriate, to obtain AOBP readings. The Microlife WatchBP Office device has been validated for OBP measurement by the International Protocol.12 The device was programmed to take the first reading with the physician in the room to verify that the cuff was correctly positioned and to confirm the validity of the BP reading. This first reading was then discarded. Subsequently, the patient was lead into the examination room and seated on an upright chair with arms supported by adjustable armrests at heart level and feet uncrossed on the floor. The patient was left alone to rest for 5 min to eliminate the white-coat effect, after which the device was remotely activated from a PC in the adjoining office via a Bluetooth connection to commence triplicate automated simultaneous measurement of both arms. The device was set to record BP at 1 min intervals (timed from the start of one reading to the start of the next). All six readings were used to determine the mean AOBP.

To test the accuracy of ambulatory and automated BP devices, readings were compared at each session against a standard mercury sphygmomanometer to confirm that there was no consistent difference >10 mm Hg.

An algorithm proposed by Myers6 was used in which for both ABPM and AOBP readings the proposed reference standard was set at three levels: optimum BP (<130 mm Hg and/or <80 mm Hg), hypertensive (≥140 mm Hg and/or ≥90 mm Hg), and borderline BP (130–139 mm Hg and/or 80–89 mm Hg).

Echocardiographic measurements. Two-dimensional guided M-mode echocardiography was performed based on the American Society of Echocardiography recommendations. End-diastolic dimensions were used to calculate the LVM using the Devereux and Reichek formula:13

LVM (g) = (1.04 (LVEDD + IVST + PWT)^3) – (LVEDD)^3) + 0.6

LVEDD represents LV end-diastolic internal dimension, whereas IVST and PWT indicate the end-diastolic thickness of the interventricular septum and LV posterior wall, respectively. The LVM was normalized with the individual’s body surface area (BSA) in m² (LVM_BSA). LV hypertrophy was defined as LVM indexed to a BSA exceeding 125 g/m² in men and 110 g/m² in women.14 LV relative wall thickness was calculated as twice the PWT divided by the LVEDD. Concentric LV hypertrophy was determined as LV hypertrophy with a relative wall thickness of at least 0.42.15

The LV ejection fraction was estimated as the percentage of reduction in LV volume from end-diastole and end-systole. Fractional shortening of the LV mid-wall was established according to the findings of the de Simone and Devereux report.16 The LVM was also normalized by division with height².7 (LVM_H²).17

Statistical analysis. Continuous variables are presented as mean ± s.d. For the analyses of the AOBP measurements, we used the mean of both right and left arms. Awake systolic and diastolic ABPM readings were compared with the AOBP and OBP readings using Bland–Altman plots.18 Bias, defined as the mean difference of the measurements, and the 95% limits
of agreement are reported. The relation between AOBP and awake ABPM measurements with $LVM_{BSA}$ and $LVM_H$ was assessed using Pearson’s correlation coefficient. We calculated sensitivity, specificity, positive and negative predictive value of ABPM and AOBP in determining LV hypertrophy. We used receiver operating characteristic curves to determine optimal cutoff points. All analyses were performed using SPSS version 17 (SPSS, Chicago, IL).

RESULTS

From September 2009 to July 2010, 94 consecutive subjects were evaluated for inclusion in the study. A total of 90 subjects were enrolled, including 44 men and 46 women with a mean age of $54 \pm 14$ years. Four subjects were excluded as their OBP readings were within normal limits. AOBP and awake systolic ABPM data were obtained from the 90 patients. Overall, individuals had a high body mass index; ~40% were overweight ($25–29.9$ kg/m$^2$), while almost 43% were obese ($\geq 30$ kg/m$^2$). Approximately 6.7% either had diabetes mellitus or hemoglobin A1C >7%. The characteristics of all patients are shown in Table 1.

The mean number of valid measurements used to compute the mean awake SBP and DBP was $60 \pm 13$. The mean awake SBP was $136 \pm 16$ mm Hg, and the mean of six (three per arm) AOBP SBP readings was $140 \pm 15$ mm Hg ($P = 0.002$). Likewise, the mean awake DBP was $87 \pm 11$ mm Hg and the mean of six (three per arm) AOBP DBP readings $88 \pm 12$ mm Hg ($P = 0.08$). In contrast, OBP recorded in the office by the study physician was $163 \pm 19$ and $96 \pm 11$ mm Hg for SBP and DBP, respectively. Differences of OBP with AOBP and awake ABP measurements were statistically significant ($P < 0.001$).

The agreement between awake ambulatory SBP and office readings (OBP SBP and AOBP SBP) was examined using Bland–Altman plots. There was a positive bias for the mean OBP SBP readings of $27.6 \pm 25.2$ mm Hg with 95% limits of agreement $-22.9$ mm Hg to $78.1$ mm Hg (Figure 1), as opposed to the mean difference of AOBP SBP readings with awake ambulatory SBP which was only $4.1 \pm 12.2$ mm Hg with corresponding 95% limits of agreement $-20.2$ mm Hg to $28.4$ mm Hg (Figure 2). Similarly, there was a positive bias for the mean OBP DBP readings of $9.4 \pm 15.5$ mm Hg with 95% limits of agreement $-20.2$ mm Hg to $28.4$ mm Hg (Figure 3).

### Table 1 | Characteristics of the studied subjects

| Number (n) | 90 |
| Race | Caucasian |
| % Women | 46 |
| Current smokers | 37 (41%) |
| Former smokers | 18 (20%) |
| Age (years) | $54 \pm 14$ |
| BMI (kg/m$^2$) | $30 \pm 6$ |
| BSA (m$^2$) | $1.9 \pm 0.3$ |
| OBP SBP (mm Hg) | $163 \pm 19$ |
| OBP DBP (mm Hg) | $96 \pm 11$ |
| AOBP SBP (mm Hg) | $140 \pm 15$ |
| AOBP DBP (mm Hg) | $88 \pm 12$ |
| Awake SBP (mm Hg) | $136 \pm 16$ |
| Awake DBP (mm Hg) | $87 \pm 11$ |
| Asleep SBP (mm Hg) | $124 \pm 15$ |
| Asleep DBP (mm Hg) | $75 \pm 12$ |
| 24-h SBP (mm Hg) | $132 \pm 14$ |
| 24-h DBP (mm Hg) | $83 \pm 11$ |
| Awake HR (bpm) | $80 \pm 10$ |
| Asleep HR (bpm) | $69 \pm 10$ |
| 24-h HR (bpm) | $76 \pm 9$ |

AOBP, automated office blood pressure; BMI, body mass index; bpm, beats/min; BSA, body surface area; DBP, diastolic blood pressure; HR, heart rate; OBP, office blood pressure; SBP, systolic blood pressure.

**Figure 1** | Bland–Altman plots of differences between systolic office blood pressure (OBP) and awake ambulatory systolic blood pressure (SBP). Mean differences are shown in solid lines with ±2 s.d. in dashed lines.

**Figure 2** | Bland–Altman plots of differences between automated systolic office blood pressure (AOBP) and awake ambulatory systolic blood pressures (SBP). Mean differences are shown in solid lines with ±2 s.d. in dashed lines.
limits of agreement −20.9 mm Hg to 39.8 mm Hg (Figure 3). In contrast, the mean difference of AOBP DBP readings with awake ambulatory DBP was only 1.1 (±7.9) mm Hg with corresponding 95% limits of agreement −14.4 mm Hg to 17.0 mm Hg (Figure 4). The correlation coefficients of OBP and AOBP with ABPM are shown in Tables 2 and 3.

Based on the algorithm for AOBP as defined by Myers, 6 49 patients with SBP ≥140 mm Hg and/or DBP ≥90 mm Hg were classified as hypertensives, 28 patients with SBP 130–139 mm Hg and/or DBP 80–89 mm Hg as borderline, and 13 patients with SBP <130 mm Hg and/or DBP <80 mm Hg as normotensives. If an optimum ABP is defined as SBP <130 mm Hg and DBP <80 mm Hg, then only 3 of the 49 classified as hypertensives (6%) would have been categorized as having white-coat hypertension. Of the 13 patients that were classified as normotensives based on the AOBP readings, none displayed masked hypertension, based on subsequent ambulatory measurements.

LVM_{BSA} was 103.8 ± 36.6 g/m² and LVM_H was 49.8 ± 18.2 g/m².7 Eleven men and six women (19% of the total population) had LV hypertrophy as confirmed by echocardiography. The correlation coefficients and statistical significance between BP measurements and LVM indices are given in Table 4. Supplementary Figures S1 and S2 online show the scatter plots of LVM_{BSA} with AOBP and awake SBP measurements. The diagnostic characteristics of the ambulatory and AOBPs measurements regarding the presence of LV hypertrophy in our sample are presented in Table 5.

**Table 2 | Correlation coefficients and P values for systolic OBP, AOBP, and ambulatory measurements**

<table>
<thead>
<tr>
<th></th>
<th>Awake SBP</th>
<th>Asleep SBP</th>
<th>24-h SBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBP SBP</td>
<td>0.08 (0.47)</td>
<td>0.07 (0.54)</td>
<td>0.07 (0.53)</td>
</tr>
<tr>
<td>AOBP SBP</td>
<td>0.69 (&lt;0.001)</td>
<td>0.68 (&lt;0.001)</td>
<td>0.71 (&lt;0.001)</td>
</tr>
</tbody>
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AOBP, automated office blood pressure; OBP, office blood pressure; SBP, systolic blood pressure.

**Table 3 | Correlation coefficients and P values for diastolic OBP, AOBP, and ambulatory measurements**

<table>
<thead>
<tr>
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<th>Awake DBP</th>
<th>Asleep DBP</th>
<th>24-h DBP</th>
</tr>
</thead>
<tbody>
<tr>
<td>OBP DBP</td>
<td>0.007 (0.95)</td>
<td>0.03 (0.77)</td>
<td>0.02 (0.87)</td>
</tr>
<tr>
<td>AOBP DBP</td>
<td>0.78 (&lt;0.001)</td>
<td>0.72 (&lt;0.001)</td>
<td>0.80 (&lt;0.001)</td>
</tr>
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AOBP, automated office blood pressure; OBP, office blood pressure; DBP, diastolic blood pressure.

**Table 4 | Correlations of blood pressure measurements and left ventricular mass indices**

<table>
<thead>
<tr>
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<th>LVM_{BSA} (P value)</th>
<th>LVM_H (P value)</th>
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<tbody>
<tr>
<td>OBP</td>
<td>0.12 (0.25)</td>
<td>0.10 (0.34)</td>
</tr>
<tr>
<td>DBP</td>
<td>0.18 (0.09)</td>
<td>0.22 (0.04)</td>
</tr>
<tr>
<td>AOBP</td>
<td>0.37 (&lt;0.001)</td>
<td>0.34 (&lt;0.001)</td>
</tr>
<tr>
<td>AWAKE</td>
<td>0.20 (0.06)</td>
<td>0.15 (0.14)</td>
</tr>
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AOBP, automated office blood pressure; DBP, diastolic blood pressure; LVM_{BSA}, left ventricular mass normalized by division with the individual’s body surface area in m²; LVM_H, left ventricular mass normalized by the individual’s body to height².7 OBP, office blood pressure; SBP, systolic blood pressure.

**Table 5 | Blood pressure measurements with cutoff values and presence of LVH**

<table>
<thead>
<tr>
<th></th>
<th>Sensitivity</th>
<th>Specificity</th>
<th>PPV</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Awake ambulatory SBP (≥146 mm Hg)</td>
<td>0.41</td>
<td>0.90</td>
<td>0.50</td>
<td>0.86</td>
</tr>
<tr>
<td>AOBP SBP (≥151 mm Hg)</td>
<td>0.41</td>
<td>0.88</td>
<td>0.47</td>
<td>0.86</td>
</tr>
</tbody>
</table>

AOBP, automated office blood pressure; LVH, left ventricular hypertrophy; NPV, negative predictive value; PPV, positive predictive value; SBP, systolic blood pressure.
DISCUSSION
The main finding of the present study is that in a European population, systolic AOBP readings are only slightly higher than those of mean awake systolic ABP and correlate with the LVMI. In contrast, the discrepancy between systolic OBP and ABP values is considerably larger and OBP measurements do not correlate with LVM indices. The mean differences between systolic AOBP and awake systolic ABP (4 mm Hg), as well as between systolic OBP and awake systolic ABP (27 mm Hg) both reached statistical significance. The clinical implications, however, are quite different. A similar point applies also to the borderline P value of 0.08 of the diastolic measurements. The difference between the diastolic AOBP and the mean awake diastolic ABP could well reach statistical significance given a larger sample size. However, the magnitude of 1 mm Hg difference clearly can have only marginal clinical relevance.

In our study, systolic AOBP measurements were in average 4 mm Hg higher than the ambulatory values. In another study, this difference was somewhat smaller. A possible explanation for this could be that different measuring devices were used in the two studies.

It is known that the accuracy of manual measurements taken by physicians as part of routine clinical practice, which often provide the basis for decisions made regarding diagnosis and treatment is compromised by artificial increases in BP, such as nonstandardization of BP measurements between observer or site, observer error, or an inappropriate environment. In addition to the technical aspect, readings can be influenced by patient anxiety, otherwise known as the white-coat effect. Moreover, manual measurements cannot accurately predict LVM as closely as ABP measurements. Studies using semi- or fully automatic devices and nurse-recorded auscultatory BP values have compared the potential of conventional BP readings against ABP measurements to predict cardiovascular events and concluded that ABPM was superior. Correlations have been shown between special physician’s office and ABPM readings but not between routine office and ABPM readings. Similarly, LVM index had a higher correlation with both special physician’s office and ABPM readings than with routine office readings. A recent study showed that manual sphygmomanometer readings can be replaced by AOBP readings; developments in AOBP technology have enhanced the validity of office readings. Furthermore, AOBP readings reduced measurement error, as well as bias on the part of the observer and showed slightly lower readings due to reduced observer-subject interaction (the white-coat effect). Another recent study demonstrated that mean AOBP readings obtained before, after, and during the visit to ABPM unit, were consistent from visit to visit regardless of the setting in which they were taken and they were similar to the mean awake ABP. In contrast, BP reading in the office taken by a technician was significantly higher than the mean awake ABP.

The independent effects of both conventional and ABP have been reported to indicate target organ changes in patients with diabetes mellitus. To our knowledge, there is an absence of studies exploring whether AOBP values are equally associated with LVM index as those of ABP. The present study is the first to show such an association. Another interesting finding in our study is that LVM is more closely related to SBP than to DBP. This finding is in line with current views that wall stress, which is mostly related to SBP, is critical in LV hypertrophy development.

The forthcoming discontinuation of mercury from the workplace over environmental concerns creates a potential role for AOBP as an alternative to manual BP measurement in the office. Home BP and 24-h ABPM measurements have been proposed as possible solutions to problems associated with routine manual BP readings. AOBP measurements offer a third option that would maintain the role of BP measurement in the physician’s office. According to the 2010 Canadian Hypertension Education Program recommendations for the management of hypertension, AOBP has been recognized as a valuable tool in hypertension diagnosis and AOBP measurements ≥135/85 mm Hg should be considered analogous to a mean awake ABP ≥135/85.

Our study shows a possible complementary role that could be played by AOBP in evaluating cardiac remodeling. An explanation for this correlation is not readily apparent. It is plausible that LVM indices are strongly determined by daytime resting BP, particularly SBP, and AOBP readings are always taken at daytime resting. A similar explanation was proposed in a study of nurse-recorded auscultatory BP vs. ABPM in an African population.

This cross-sectional study is not without its limitations. Greater numbers of normotensive and hypertensive patients undergoing AOBP, 24-h ABPM, and echocardiography measurements are needed before these results can be considered as representative of the overall population. Although an electronic device was chosen to avoid bias in OBP measurements, it could be perceived as a limitation in the generalization of our results in routine clinical practice.

In conclusion, AOBP readings appear to compare favorably with 24-h ABPM in the appraisal of LVM index and as such could be complementary to ABPM in the same way that home BP is. However, outcome-based studies would be necessary to assess the value of AOBP as a predictor of cardiovascular morbidity and mortality.

Supplementary material is linked to the online version of the paper at http://www.nature.com/ajh

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Disclosure: The authors declared no conflict of interest.


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