Comparing differences and correlation between 24-hour ambulatory blood pressure and office blood pressure monitoring in patients with untreated hypertension

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Abstract
Objective: We assessed differences and correlations between 24-hour ambulatory blood pressure (ABP) and office blood pressure (OBP) monitoring.

Methods: We conducted an observational study among 85 untreated patients with essential hypertension and measured 24-hour ABP, OBP, target organ damage (TOD) markers, and metabolism indexes. Variance analysis and the Pearson method were used to compare differences and correlation between the two methods. The Spearman or Pearson method was applied to compare the correlation between TOD markers, blood pressure index, and metabolism index. Linear regression analysis was applied to estimate the quantitative relationship between the blood pressure index and TOD markers.

Results: There were significant differences in the mean and variance of systolic blood pressure (SBP) and diastolic blood pressure and a positive correlation between ABP and OBP. Correlations between the left ventricular mass index (LVMI) and average ambulatory SBP, daytime ambulatory SBP, nighttime ambulatory SBP, and fasting blood glucose were significant. Correlations between left intima-media thickness (IMT) and average ambulatory SBP, nighttime ambulatory SBP, right IMT, and nighttime ambulatory SBP were significant. In linear regression analysis of the LVMI (y) and ambulatory SBP (x), the equation was expressed as \( y = 0.637^*x \).

Conclusion: Nighttime ambulatory SBP may be an optimal predictor of TOD.

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Keywords
Ambulatory blood pressure, monitoring, target organ damage, office blood pressure, left ventricular mass index, carotid intima thickness

Introduction
Blood pressure is traditionally monitored in a clinic by a doctor or nurse. The diagnosis and treatment of hypertension are usually based on office blood pressure (OBP) monitoring. With rapid developments in information technology and telecommunications in the medical field, ambulatory blood pressure (ABP) monitoring, first used in 1904, is becoming more frequently used to assess individual blood pressure. ABP monitoring has the potential to improve the control of hypertension. Monitoring of OBP and ABP have specific advantages and disadvantages in clinical practice. Studies have investigated these methods, but the study protocols and findings were not homogeneous. There is still no agreement among the various guidelines about the use of ABP monitoring in clinical practice. For example, National Institute for Health and Care Excellence (NICE) guidelines and Chinese guidelines recommend that ABP monitoring should be offered to all patients with suspected hypertension. However, European guidelines recommend that ABP monitoring should only be an option in selected cases. Hence, the first aim of this study was to evaluate the relationship between OBP and ABP, especially looking at which blood pressure index is superior in predicting target organ damage (TOD). The second study aim was to elucidate the prognostic significance of TOD assessed using two blood pressure monitoring systems independently. Our study findings may provide valuable information regarding the use of ABP monitoring in clinical practice.

Methods
This was a cross-sectional observational study. Participant recruitment was conducted from 1 August 2018 to 31 December 2018 by five doctors at the Affiliated Hospital of Foshan, Southern Medical University. The sample size was calculated using the correlation module in PASS 11.0 software (NCSS LLC, East Kaysville, UT, USA) (α = 0.05, β = 0.90), according to a 15% refusal rate and participant drop out.

Study participants
Patients with untreated hypertension (including those taking medication or receiving life guidance therapy) were eligible to participate in the study. Exclusion criteria were patients with: 1) cardiac function grade IV and acute left heart failure, according to New York Heart Association classification; 2) secondary hypertension; 3) primary cardiomyopathy; 4) acute cerebral vascular accident; 5) chronic renal insufficiency; 6) chronic respiratory disease; 6) cirrhosis and acute or chronic hepatitis; 7) diabetes, hyperthyroidism, and other endocrine and metabolic diseases; 8) anemia owing to heart disease; 9) mild to moderate anemia; 10) congenital heart disease and valvular heart disease; and 11) patients...
who did not agree to provide informed consent.

**Blood pressure measurements**

OBP was monitored in the clinic using the same device (HEM-6111; Omron, Kyoto, Japan) and calculated as the average of three consecutive measurements. ABP was recorded using an automatic electronic device (Oscar 2; SunTech Medical Inc., Morrisville, NC, USA) during the daytime (6.00 a.m. to 10.00 p.m.) at 30-minute intervals and during the night (10.00 p.m. to 6.00 a.m.) at 60-minute intervals. The average was taken over 24 hours; daytime and nighttime blood pressure were calculated using hourly data. These measurements were taken prior to the administration of antihypertensive medication.

**Target-organ damage (TOD) marker measurements**

The left ventricular mass index (LVMI), carotid intima-media thickness (IMT), and urinary albumin–creatinine ratio (UACR) are recognized markers of heart, vascular, and kidney damage caused by hypertension, respectively. Therefore, as markers of TOD, we measured these in our study. The LVMI and IMT measurements were performed under quiet and warm conditions. The right and left carotid arteries were imaged using a high-resolution color Doppler ultrasound imaging instrument (Philips iE33; Netherlands) by an experienced ultrasonographer. Values of the LVMI and IMT were computed and outputted automatically by the instrument. Urine samples were collected when patients enrolled in the study. The UACR was measured using a turbidimetric immunoassay (Beckman AO5421 fully automatic biochemistry analyzer; Abbott, Chicago, IL, USA).

**Metabolism index**

Blood lipids, glycated hemoglobin (HbA1C), and fasting plasma glucose (FPG) were measured as metabolism indexes. Blood samples were collected when patients enrolled in the study. High-density lipoprotein cholesterol (HDL-c), low-density lipoprotein cholesterol (LDL-c), and FPG were measured using the Beckman AO5421 biochemistry analyzer. HbA1C was measured with a TOSOH HLC 723GB automatic glycohemoglobin analyzer (Abon, Japan).

**Statistical analysis**

The data were analyzed using IBM SPSS 21.0 software (IBM Corp., Armonk, NY, USA). Data are expressed as mean ± standard deviation or median and interquartile range. First, we used the Kolmogorov–Smirnov method to perform normality tests for values of the various indicators. Second, analysis of variance or a nonparametric Kruskal–Wallis test was performed to detect differences between the two blood pressure monitoring methods. Third, Pearson or Spearman correlation coefficients were determined to assess a possible relationship between the two monitoring methods. Fourth, Spearman or Pearson methods were applied to identify correlations between TOD and the values of blood pressure indexes (OBP, average ABP, daytime ABP, nighttime ABP) and metabolism indexes (blood lipids, HbA1C, FPG), respectively. Furthermore, linear regression analysis was used to search for linear and quantitative dependence between values of blood pressure indexes and TOD. All tests were two-sided and a P-value less than 0.05 indicated statistical significance.

**Ethics**

The ethics committee of the Affiliated Hospital at Foshan, Southern Medical
University approved the protocol. Patients who agreed to participate in this study signed informed consent forms and were registered in a Chinese clinical trial registry (http://www.chictr.org.cn, Registry NO: ChiCTR-OOC-16008944).

**Results**

**Patient characteristics**

Eighty-five patients with untreated hypertension agreed to participate and provided an informed consent form; all participants were older than 18 years of age. The characteristics of the study population are reported in Table 1.

**Normality tests for various indicator values**

The values of blood pressure, LVMI, HDL-c, LDL-c, and HbA1C had a normal distribution whereas those of the IMT (right), IMT (left), UACR, and FBG had a non-normal distribution. Variance analysis was used to compare the difference between blood pressure monitoring methods, and Pearson correlation coefficients were determined to assess possible relationships between the two methods. The Pearson method was applied to find the correlation between the LVMI and values of blood pressure indexes HDL-c, LDL-c, and HbA1C, respectively. Alternatively, the Spearman method was applied to find the correlation between the IMT or UACR and the value of blood pressure index, FBG.

**Office blood pressure (OBP) monitoring versus ambulatory blood pressure (ABP) monitoring**

The mean systolic blood pressure (SBP) and diastolic blood pressure (DBP) were higher using OBP than ABP (148.13 ± 18.75 mmHg vs. 132.61 ± 14.04 mmHg; 79.01 ± 14.14 mmHg vs. 73.92 ± 10.03 mmHg; respectively; P < 0.01 for both). The mean SBP and DBP of OBP were also higher than those of daytime ABP (148.13 ± 18.75 mmHg vs. 134.54 ± 14.50 mmHg; 79.01 ± 14.14 mmHg vs. 75.42 ± 10.70 mmHg, respectively; P < 0.05 for both). Blood pressure measurements were highly correlated between the two methods (Pearson correlation coefficients between the two methods were r = 0.561 and 0.675 for SBP and DBP, respectively; P < 0.001 for both).

| Table 1. Participant characteristics. |
|---------------------------------------|
| N | Value                  |
|---|------------------------|
| Age | 85 | 67.32 ± 10.6 years |
| OBP |          |                      |
| SBP | 85 | 148.13 ± 18.75 mmHg |
| DBP | 85 | 79.01 ± 14.14 mmHg |
| Average BP |          |                      |
| SBP | 85 | 132.61 ± 14.04 mmHg |
| DBP | 85 | 73.92 ± 10.03 mmHg |
| Daytime ABP |          |                      |
| SBP | 85 | 134.54 ± 14.50 mmHg |
| DBP | 85 | 75.42 ± 10.70 mmHg |
| Nighttime ABP |          |                      |
| SBP | 85 | 125.53 ± 17.59 mmHg |
| DBP | 85 | 69.20 ± 10.32 mmHg |
| LVMI | 84 | 84.88 ± 22.15 g/m² |
| IMT (left) | 70 | 0.98 mm |
| IMT (right) | 70 | 0.98 mm |
| UACR | 82 | 1.90 mg/mmol |
| LDL-c | 83 | 2.73 ± 0.82 mmol/L |
| HDL-c | 83 | 1.46 ± 0.47 mmol/L |
| FBG | 83 | 5.34 mmol/L |
| HbA1C | 81 | 5.71 ± 0.40% |

Note: Data are expressed as mean ± standard deviation or median.

OBP, office blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; ABP, ambulatory blood pressure; LVMI, left ventricular mass index; IMT, intima-media thickness; UACR, urinary albumin–creatinine ratio; LDL-c, low-density lipoprotein cholesterol; HDL-c, high-density lipoprotein cholesterol; FBG, fasting blood glucose; HbA1C, glycated hemoglobin.
Correlation analysis of TOD, blood pressure monitoring systems, and metabolism indexes

First, we assessed possible correlations between the LVMI and values of the two blood pressure monitoring systems, HDL-c, LDL-c, FPG, and HbA1C. The average ambulatory SBP (Pearson correlation coefficient $r = 0.527$, $P = 0.013$), daytime ambulatory SBP (Pearson’s $r = 0.559$, $P = 0.014$), nighttime ambulatory SBP (Pearson’s $r = 0.239$, $P = 0.032$), and FPG (Spearman’s $r = 0.224$, $P = 0.042$) were significantly positively correlated with the LVMI. Correlation analysis of blood pressure and the LVMI are shown in Table 2. The correlation between the LVMI and other indicators was not significant (data not shown).

Second, we assessed possible correlations between the IMT, blood pressure, and metabolism indexes. The average ambulatory SBP (Spearman’s $r = 0.244$, $P = 0.042$) and nighttime ambulatory SBP (Spearman’s $r = 0.377$, $P = 0.001$) were significantly positively correlated with the left IMT. Correlation analysis of blood pressure and the left IMT are shown in Table 3. Similarly, nighttime ambulatory SBP (Spearman’s $r = 0.312$, $P = 0.009$) was significantly positively correlated with right IMT. Results of correlation analysis for blood pressure and right IMT are shown in Table 4.

Third, we assessed possible correlations between the UACR, blood pressure, and metabolism indexes. There were no statistical correlations between the UACR and all indicators.

### Linear regression analysis

From the above results, we deemed that the average ambulatory SBP, daytime

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#### Table 2. Correlation analysis of blood pressure and LVMI.

| LVMI          | $r$ (N = 84) | P-value |
|---------------|-------------|---------|
| OBP (SBP)     | 0.145       | 0.1894  |
| OBP (DBP)     | −0.065      | 0.556   |
| ABP (SBP)     | 0.527       | 0.013   |
| ABP (DBP)     | 0.113       | 0.306   |
| ABP (D-SBP)   | 0.559       | 0.014   |
| ABP (D-DBP)   | 0.119       | 0.280   |
| ABP (N-SBP)   | 0.239       | 0.032   |
| ABP (N-DBP)   | 0.106       | 0.339   |

Note: Pearson’s correlation coefficients.
LVMI, left ventricular mass index; OBP, office blood pressure; ABP, ambulatory blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; D-, daytime; N-, nighttime.

#### Table 3. Correlation analysis of blood pressure and left IMT.

| left IMT | $r$ (N = 70) | P-value |
|----------|-------------|---------|
| OBP (SBP)     | 0.146       | 0.228   |
| OBP (DBP)     | −0.153      | 0.207   |
| ABP (SBP)     | 0.244       | 0.042   |
| ABP (DBP)     | −0.095      | 0.436   |
| ABP (D-SBP)   | 0.206       | 0.088   |
| ABP (D-DBP)   | −0.123      | 0.310   |
| ABP (N-SBP)   | 0.377       | 0.001   |
| ABP (N-DBP)   | 0.091       | 0.454   |

Note: Spearman’s correlation coefficients.
IMT, intima-media thickness; OBP, office blood pressure; ABP, ambulatory blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; D-, daytime; N-, nighttime.

#### Table 4. Correlation analysis of blood pressure and right IMT.

| right IMT | $r$ (N = 70) | P-value |
|-----------|-------------|---------|
| OBP (SBP)     | 0.085       | 0.484   |
| OBP (DBP)     | −0.156      | 0.196   |
| ABP (SBP)     | 0.189       | 0.117   |
| ABP (DBP)     | −0.130      | 0.285   |
| ABP (D-SBP)   | 0.146       | 0.227   |
| ABP (D-DBP)   | −0.163      | 0.178   |
| ABP (N-SBP)   | 0.312       | 0.009   |
| ABP (N-DBP)   | 0.031       | 0.797   |

Note: Spearman’s correlation coefficients.
IMT, intima-media thickness; OBP, office blood pressure; ABP, ambulatory blood pressure; SBP, systolic blood pressure; DBP, diastolic blood pressure; D-, daytime; N-, nighttime.
ambulatory SBP, and nighttime ambulatory SBP are associated with TOD. Furthermore, to estimate quantitative relationships between various blood pressure indexes and TOD, we used linear regression analysis (standard method). There was a significant linear and quantitative relationship between average ambulatory SBP and the LVMI (P < 0.05). This statistical relationship also existed between nighttime ambulatory SBP and IMT (P < 0.05). When linear regression analysis was applied to the LVMI (y) and average ambulatory SBP (x), the equation was expressed as y = 0.637*x. When linear regression analysis was applied to IMT (y) and nighttime ambulatory SBP (x), the equations were expressed as y (left) = 0.460 + 0.004*x and y (right) = 0.471 + 0.004*x. The other blood pressure index could not be introduced into the equation.

Discussion

A main finding of this study revealed that OBP was significantly higher than ABP in a number of untreated patients with hypertension. The primary reason for this is that ABP responds to 24-hour blood pressure, including nocturnal blood pressure troughs, rather than instantaneous blood pressure. OBP was also higher than daytime ABP. Intrinsic characteristics of OBP, such as patient anxiety in the office setting, may explain the above finding. Classic OBP is the gold standard for screening, diagnosing, and managing hypertension, but it is constrained by several factors including white-coat hypertension and nocturnal hypertension. In contrast to OBP, ABP monitoring is a useful tool in diagnosing masked hypertension, nocturnal hypertension, and white-coat hypertension.13–18 In our study, the proportion of patients with nocturnal hypertension was as high as 78% (58/85) and isolated nocturnal hypertension was 8.2% (7/85). However, ABP is also constrained by factors such as sleep disturbance in many patients.19–21 Our results provide useful information for the management of hypertension in terms of understanding the characteristics of the two blood pressure monitoring methods. There is a highly positive correlation between these methods, and our results indicate that they are closely related but not identical. OBP monitoring forms the basis for the treatment and management of hypertension. Monitoring of ABP can supplement, rather than replace, OBP monitoring. Use of ABP has several advantages,1 especially because multiple blood pressure measurements are taken in one day so the data are more detailed, enabling treatment to be adjusted based on the individual’s blood pressure fluctuations over a day.

The information revealed in this analysis is that ABP is more closely associated with indices of subclinical TOD than OBP in untreated patients with hypertension. To compare the predictive effect of the two blood pressure measurement methods on TOD, we monitored the correlation coefficient between markers of TOD and these methods. We found that (1) the average SBP, daytime ambulatory SBP, and nighttime ambulatory SBP were significantly positively correlated with the LVMI; (2) the average ambulatory SBP and nighttime ambulatory SBP were significantly positively correlated with left IMT; and (3) nighttime ambulatory SBP was significantly positively correlated with right IMT. Additionally, linear regression analysis showed a linear and quantitative relationship between the LVMI and average ambulatory SBP and the IMT and ambulatory nighttime SBP. Unfortunately, we found no statistical correlations between the UACR and values of the two blood pressure measurement methods. We cannot provide a convincing explanation for this unexpected finding. However, we concluded that ABP has a superior ability to predict hypertensive TOD in comparison with
OBP, based on the above findings. Several clinical studies\textsuperscript{22–25} have shown that ABP values predict cardiovascular risk better than OBP. Additionally, a consistent finding in this study was that ABP was more closely associated with indices of subclinical TOD in untreated patients with hypertension. In short, the findings of this study may provide objective evidence regarding the value of ABP in the prediction of hypertension-induced TOD.\textsuperscript{26–28}

In our study, nighttime ambulatory SBP was a superior predictor in terms of its association with TOD. This conclusion is supported by previous studies.\textsuperscript{27,29,31} When examining the correlation between specific components of 24-hour blood pressure and TOD, we found that nighttime ambulatory SBP was closely correlated to the LVMI, left IMT, and right IMT. Recently there have been many reports that cardiovascular risk and TOD in patients with nocturnal hypertension are greater than in those with normotensive blood pressure at night and that good control of nighttime blood pressure is important for preventing cardiovascular disease and protecting against TOD.\textsuperscript{30} The present study adds to the evidence showing that nighttime ambulatory SBP has a strong prognostic value for TOD.

A main limitation in this study was that OBP monitoring was done casually, without multiple measurements taken on the same day, thereby reducing the conclusiveness of our research results. Moreover, this study failed to prove the blood pressure predictive value of the UACR, which might weaken the conclusions. Finally, the study design was cross-sectional and observational; therefore, some inherent bias could not be completely excluded.

**Conclusion**

Our study findings provide a small but valuable contribution to the practice of ABP monitoring in a clinical setting. We offer further support for the usefulness of assessing specific components of ABP monitoring in clinical practice. Second, our findings allow for a better understanding of preferred therapies for controlling nighttime blood pressure and reducing the risk of TOD. Finally, the present results provide hints as to further research involving patients with treated or refractory hypertension, to reach more comprehensive conclusions.

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**Declaration of conflicting interest**

The authors declare that there is no conflict of interest.

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