Hemodynamics in White Coat Hypertension Compared to Ambulatory Hypertension and Normotension

Johannes Soma, Soend Aakhus, Ketil Dahl, Stig Slørdahl, Rune Wiseth, Tor Erik Widerøe, and Terje Skjærpe

Hemodynamic alterations associated with the blood pressure response in subjects with white coat hypertension may provide insight into the pathophysiologic mechanisms of this condition. Systemic arterial hemodynamics were investigated with a recently validated method based on noninvasive estimates of aortic root pressure and flow in 28 subjects with white coat hypertension (diastolic pressure ≥ 90 mm Hg measured by the general practitioner [GP arterial pressure] and ambulatory daytime pressures < 140/90 mm Hg), in 23 subjects with previously untreated, ambulatory hypertension (GP diastolic pressure ≥ 90 and < 115 mm Hg and ambulatory daytime diastolic pressure ≥ 90 mm Hg), and in 32 normotensive subjects. The groups did not differ significantly concerning age, gender, body surface area, heart rate, stroke index and cardiac index, but total peripheral resistance index was increased and total arterial compliance reduced in the white coat group and the hypertensive group compared to the normotensive group. The subjects in the white coat group with a systolic arterial pressure during echocardiography that was > 5 mm Hg higher than the ambulatory daytime systolic pressure (n = 19) had increased cardiac index, increased total peripheral resistance, and decreased total arterial compliance compared to the normotensive group. The subjects in this group with a hemodynamic pattern characterized by a high ratio of cardiac index/peripheral vascular resistance were significantly younger than the subjects with the opposite pattern. Thus, the blood pressure increase in subjects with white coat hypertension is associated with increased cardiac output, increased peripheral vascular resistance, and reduced total arterial compliance, but the hemodynamic pattern may be influenced by age. Am J Hypertens 1996; 9:1090-1098

KEY WORDS: White coat hypertension, ambulatory blood pressure, hemodynamics, Doppler echocardiography, calibrated subclavian artery pulse trace.

Subjects with white coat hypertension are characterized by elevated arterial pressures in the physician’s office, but “normal” pressures at other times. Several studies have indicated a good prognosis of this condition by demonstrating a low degree of end-organ damage. The consequence is that subjects with white coat hypertension, which may represent 20% to 60% of a hypertensive population, may have a confounding effect in studies of heart disease as well as in clinical practice. However,
others have shown that subjects with this condition exhibit end-organ damage and metabolic characteristics that differ from normal. It is therefore controversial whether subjects with white coat hypertension need increased medical surveillance or treatment.

The aim of this study was to investigate the pathophysiological mechanisms that generate the white coat blood pressure response. To accomplish this, we used a recently validated method based on noninvasive estimation of aortic root pressure and flow. Subjects who were evaluated as hypertensives by the general practitioner, but who had "normal" ambulatory daytime arterial pressures, were recruited for this study. Arterial blood pressures were in addition measured by a nurse according to a standardized procedure and during the echocardiographic examination. Hemodynamic variables obtained during echocardiography were evaluated in relation to the blood pressure response achieved during that examination.

METHODS

Study Subjects The study comprised three study groups that were not significantly different regarding age, gender and body surface area (Table 1). The white coat group consisted of 28 subjects with diastolic pressure in the general practitioner's office (GP arterial pressure) = 90 mm Hg and ambulatory daytime arterial pressure < 140/90 mm Hg (Table 1). The main reasons for referral to the special ward for hypertension in our hospital were a tendency to blood pressure variability, increased heart rate associated with measurement of arterial pressure, young age, or an unspecified wish from the patient or from the physician to obtain a thorough evaluation before the start of medical therapy. Subjects who fulfilled the inclusion criteria were consecutively referred for echocardiography for evaluation of inclusion in the study. Three of the referred subjects were excluded, one because of valvular heart disease and two because of a poor echocardiographic window. Two subjects used antihypertensive medication that was stopped at least 4 weeks before inclusion. The remaining 26 subjects were previously untreated.

The group with ambulatory hypertension (hypertensive group) consisted of 23 previously untreated subjects with GP diastolic pressure ≥ 90 and < 115 mm Hg and ambulatory daytime diastolic pressure ≥ 90 mm Hg. These subjects were recruited directly from general practitioners with the aim of participating in a study of hemodynamics in hypertension. Twenty-four subjects with previously untreated, ambulatory hypertension were referred for echocardiography. One subject was excluded because of an inappropriate echocardiographic window.

All subjects in our database of normotensive, healthy subjects in the same age range as the hypertensive group were selected as controls for this study. Most subjects in that age range entered the database by a random selection of employees in the hospital. The normotensive group consisted of 32 subjects with diastolic pressure < 90 mm Hg measured by a nurse in the clinic. This pressure was determined in accordance with the requirements for the clinic arterial pressure as described below, but was performed on one day only.

Exclusion criteria for all groups were evidence of coronary heart disease, heart failure, valvular heart disease, atrial fibrillation, chronic obstructive pulmonary disease, secondary hypertension, other major diseases, use of drugs, inappropriate echocardiographic window, and the inability to obtain a subclavian pulse trace.

All subjects gave written informed consent to the investigation, which was approved by the regional ethical committee.

Arterial Blood Pressure Measurements GP Arterial Pressures GP arterial pressures were measurements of brachial arterial pressures obtained in the general practitioner's office by the physician. The requirements for recording and analysis of these pressures were in accordance with the guidelines from The Norwegian College of General Practitioners. If several pressures were presented at admittance in the clinic, an average of these was calculated.

Clinic Arterial Pressures Clinic arterial pressures were measured in the clinic with a mercury sphygmoma-

### TABLE 1. GROUP CHARACTERISTICS

<table>
<thead>
<tr>
<th></th>
<th>Normotension</th>
<th>White Coat</th>
<th>Ambulatory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (men/women)</td>
<td>19/13</td>
<td>16/12</td>
<td>14/9</td>
</tr>
<tr>
<td>Age (years)</td>
<td>48 ± 7</td>
<td>47 ± 13</td>
<td>48 ± 7</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.90 ± 0.20</td>
<td>1.90 ± 0.18</td>
<td>1.95 ± 0.17</td>
</tr>
<tr>
<td>LVMI (g/m²)</td>
<td>90 ± 20</td>
<td>103 ± 36</td>
<td>121 ± 24*</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

* P < .05 v normotension and v white coat hypertension.

LVMI: left ventricular mass index, which was suitable for analysis in 29 normotensive subjects, 25 subjects with white coat hypertension, and 21 subjects with ambulatory hypertension.
nometer by an experienced nurse. Korotkoff phase V was used to determine the diastolic pressure. These measurements were obtained with the subject in the sitting position after resting for at least 15 min. They were performed on 3 different days with 1 week in between measurements. The two lowest of the three readings on each day were averaged and the average of the two lowest averages determined the clinic arterial pressures.

An ambulatory 24-h arterial blood pressure recording (Oxford, Medilog ABP, Oxford Medical, Inc., Clearwater, FL, or Suntech Accutracker II, Suntec Medical Instruments, Inc., Raleigh, NC) was performed on a normal work day. Ambulatory 24-h arterial pressures were defined as the mean of half-hourly recordings from 7 AM to 11 PM and hourly recordings from 12 PM to 6 AM. The nighttime recordings were missing in one subject, whereas five recordings were missing in another subject and between one and three recordings in seven other subjects. Ambulatory daytime arterial pressures were defined as the mean of half-hourly recordings from 7 AM to 11 PM. The editing of ambulatory pressures were done automatically, but manually controlled.

Oscillometric Arterial Pressures Oscillometric arterial were measurements of brachial arterial pressures recorded during the echocardiographic examination as outlined below. Clinic arterial pressures were initially measured on both arms to exclude significant deviations of arterial pressures between the right and left arm. Clinic and oscillometric arterial pressures reported in the study are all from measurements on the right arm, but the latter were recorded with the subject in the lateral decubitus position and the former with the subject in the sitting position. Ambulatory pressures were measured on the left arm except for a few cases in which the right arm was used.

Because the diastolic arterial pressures during echocardiography were considerably lower than the diastolic pressures obtained in the sitting subject, systolic pressures were used for the comparison of blood pressure responses (the increase in arterial pressure with regard to the ambulatory daytime systolic pressure) achieved during measurements of clinic pressures (Figure 1) and during echocardiography (Figure 2).

Noninvasive Data Recording All echocardiographic recordings and analysis were performed by the same investigator. The recordings were obtained with the patient in the left lateral decubitus position, and started after the patient had been at rest for at least 10 min. An ultrasound scanner (Vingmed CFM 750, Vingmed Sound, Horten, Norway) with a duplex probe (3.25-MHz imaging / 2.5-MHz Doppler) was used. The aortic anulus diameter was measured in the parasternal long axis view between the insertion points of the valve leaflets by use of the trailing-to-leading edge method. The aortic anulus flow velocities were recorded by pulsed Doppler technique from the apical position with the sample volume positioned in the centre of the outflow tract just at the anulus, obtaining an optimal

![FIGURE 1. Plots show the association and the agreement between ambulatory daytime (AMB) pressures and the corresponding clinic arterial pressures (Clinic) for the white coat group (WCH) and the hypertensive group (HT). The equations for the regression line, the coefficients of correlation and the 95% limits of agreement were as follows: A. Systolic pressures in WCH: y = 0.86x + 34; r = 0.33, P = .09; 16 ± 36. B. Systolic pressures in HT: y = 0.54x + 63; r = 0.59, P = .003; –3.5 ± 24. C. Diastolic pressures in WCH: y = 0.55x + 44; r = 0.68, P = 0.05; 10 ± 14. D. Diastolic pressures in HT: y = 0.41x + 54; r = 0.56, P = .006; –3.7 ± 14. Horizontal lines indicate mean ± 2SD.](https://academic.oup.com/ajh/article-abstract/9/11/1090/124262)
Oscillatory SP AMBcISP (mmHg)

**FIGURE 2.** Plots show the distribution of hemodynamic variables in relation to the white coat blood pressure response during echocardiography (difference between oscillometric systolic and ambulatory daytime systolic pressure). AMBd DP: Ambulatory daytime diastolic pressure; AMBd SP: Ambulatory daytime systolic pressure; S1: stroke index; CI: cardiac index; TPRI: total peripheral resistance index; C: total arterial compliance. Vertical lines indicate a white coat response of 5 mm Hg (Group B is to the left and Group A to the right of this line).

flow velocity spectral profile and a distinct valve closure signal.

The subclavian artery pulse tracings were obtained with a capillary damped funnel (Siemens-Elema AB, Solna, Sweden) positioned over the right subclavian artery at its point of maximal impulse and connected to a strain-gauge transducer (model 120-0123, Irex Medical Systems, Ramsey, NJ) and displayed simultaneously with the Doppler velocity spectre on the monitor. Only pulse traces with a consistent wave morphology, a sharp deflection in early systole, and a minimal linear drift were used. Doppler recordings and pulse traces were obtained during a short period of apnea close to end-expiration. Data from at least three consecutive cardiac cycles were transferred, together with pulse and electrocardiogram traces, to a computer for analysis (Macintosh II CI, Apple Computers Inc., Cupertino, CA).

M-mode echocardiographic images, guided by two-dimensional echocardiography, were obtained from the parasternal window and transferred to the computer.

Right brachial artery systolic and diastolic pressures were recorded with the oscillometric technique (Dinamap 1846 SXP, Criticon Inc., Tampa, FL) every minute during the Doppler ultrasound study. The measurements obtained immediately before the Doppler recordings were averaged and used for subsequent analysis.

**Analysis of Echocardiographic Recordings** Aortic root flow velocities and subclavian artery pulse traces were recorded and analyzed in all subjects (n = 83). The maximal velocity (ie, outer envelope of the Doppler spectrum) of at least three Doppler flow velocity profiles were traced manually and averaged. The subclavian artery pulse trace was calibrated with oscillometrically obtained systolic and diastolic pressures and the pulse transmission delay corrected by alignment of the pulse trace incisura to the end systole of the Doppler flow trace.

M-mode recordings were suitable for analysis in 75 subjects (M-mode recordings were rejected in three subjects in the normotensive group, three subjects in the white coat group, and two subjects in the hypertensive group). It was required that the right and the left side of the endocardial septum and the endocardial and epicardial surfaces of the posterior left ventricular wall be recorded continuously in at least three cardiac cycles.

The examiner was blinded for the arterial pressures, but not for the category of the subjects.

**Analysis of Data** The flow and pressure traces were processed by specially designed computer software in which the properties of the arterial circulation were estimated according to a three element Windkessel model of the systemic arterial tree. In this model, the total arterial compliance represents the volume compliance of the arteries, characteristic impedance is an expression of the resistance to pulsatile flow in the proximal aorta, and peripheral resistance represents the arte-
riolar resistance. Heart rate was determined from electrocardiogram (ECG) recordings during the echocardiographic investigation. Mean arterial pressure was calculated as the pressure integral over the total cardiac cycle. Pulse pressure was defined as the difference in systolic and diastolic pressures. Stroke volume was calculated as the product of the Doppler velocity-time integral and the aortic cross-sectional area assuming a circular valve annulus. Cardiac output was calculated as stroke volume times heart rate. The corresponding indices were obtained by dividing by the body surface area. Total peripheral resistance was calculated as the mean arterial pressure over cardiac output, multiplied by 80 for unit conversion. The corresponding index was obtained by multiplying by the body surface area.

Left ventricular mass was calculated from M-mode echocardiograms using the formula according to the Penn convention (Penn-cube LV mass)\textsuperscript{16}:

\[
1.04 \left( (IVSd + LVIDd + PWTd)^{3} - (LVIDd)^{3} \right) - 13.6,
\]

where LVIDd is the end-diastolic left ventricular internal diameter, IVSd is the end-diastolic intraventricular septal diameter, and PWTd is the end-diastolic posterior wall thickness. The corresponding index was obtained by dividing by the body surface area.

Statistical Analysis Continuous variables are expressed as means ± standard deviation (SD). Comparisons between the groups were performed with analysis of variance. Within group comparisons were performed with analysis of variance for repeated measurements. When the difference in the overall comparison of groups in the analysis of variance was significant (\( P < .05 \)), post hoc comparisons were performed with the Scheffé test. Relationships between variables were tested with linear regression analysis and Pearson's coefficient of correlation. The coefficient of variation (\%) was calculated as the standard deviation of the differences divided by the mean of the initial values. The 95\% limits of agreement were calculated as the mean difference ± the standard deviation of the differences × 2.\textsuperscript{17} Agreement was illustrated by plotting the differences against their average.

Reproducibility Intraobserver reproducibility of the variables of the noninvasive method used in this study were assessed by comparing measurements obtained in 30 subjects with ambulatory hypertension on two occasions, 8 weeks apart. The results for the following variables comprises variability due to recording, analysis as well as biological variability. The aortic annulus diameter obtained at the first occasion was used for calculation of hemodynamic variables at both occasions, specifically, oscillometric systolic pressure (6\%: 3 ± 18 mm Hg, coefficient of variation; 95\% limits of agreement), oscillometric diastolic pressure (8\%: 0 ± 13 mm Hg), mean arterial pressure (6\%: 1 ± 13 mm Hg), Doppler velocity-time integral of aortic root flow (7\%: 0 ± 3 cm), left ventricular stroke volume (7\%: -2 ± 15 mL), cardiac output (11\%: -0.28 ± 1.5 L), peripheral resistance (11\%: 27 ± 283 dyne/sec/cm\(^5\)), total arterial compliance (11\%: -0.04 ± 0.33 mL/mm Hg), and aortic characteristic impedance (34\%: 16 ± 44 dyne/sec/cm\(^5\)). Interobserver reproducibility of the aortic annulus diameter was assessed by comparing measurements in 16 normotensive adults on two occasions 2 weeks apart (2.5\%: 0.02 ± 0.11 cm). Interexaminer and interanalyzer reproducibility of the method have been reported previously.

RESULTS

Arterial Blood Pressures Although the subjects with white coat hypertension had significantly lower clinic and oscillometric systolic and diastolic pressures than GP systolic and diastolic pressures, the clinic systolic and diastolic pressures and the oscillometric systolic pressure were significantly higher than the respective ambulatory daytime arterial pressures, indicating that these subjects had an arterial pressure response during measurement of arterial pressures by a nurse and during echocardiography (Table 2). During the measurement of clinic arterial pressures, 19 subjects (10 men and 9 women) had a > 5 mm Hg higher systolic pressure compared with their ambulatory daytime systolic pressure (Figure 1). While a corresponding blood pressure response was shown by an equivalent number of subjects (9 men and 10 women) during echocardiography (oscillometric arterial pressures), 14 subjects showed that degree of blood pressure response on both examinations.

There was no significant difference between the white coat group and the hypertensive group concerning GP, clinic, and oscillometric systolic pressures, but the corresponding diastolic pressures were significantly lower in the white coat group (Table 2), which indicates that the pulse pressures were wider in the white coat group on all three procedures.

Figure 1 illustrates the poor relationship and agreement between ambulatory daytime arterial pressures and clinic arterial pressures in the white coat group compared to the hypertensive group. It is interesting to notice that clinic arterial pressures tended to be lower than the ambulatory daytime arterial pressures in the hypertensive group.

Hemodynamic Characteristics of the Study Groups The study groups were not significantly different concerning heart rate, stroke index, and cardiac index (Table 3). In the white coat group, but not in the other two groups, there was a significant correlation between heart rate and mean arterial pressure (\( r = 0.5, P = .009 \)). The white coat group was significantly different from the normotensive group, but not from the hypertensive group concerning total peripheral resistance index, peripheral resistance, aortic characteristic impedance, and total arterial compliance (Table 3).
### Table 2. Arterial Pressures

<table>
<thead>
<tr>
<th></th>
<th>Normotension (n = 32)</th>
<th>White Coat (n = 28)</th>
<th>Ambulatory (n = 23)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>GP SP (mm Hg)</td>
<td>118 ± 13</td>
<td>142 ± 16*</td>
<td>142 ± 12*</td>
<td>.8</td>
</tr>
<tr>
<td>GP DP (mm Hg)</td>
<td>77 ± 6</td>
<td>89 ± 8*</td>
<td>96 ± 6†</td>
<td>.002</td>
</tr>
<tr>
<td>Clinic SP (mm Hg)</td>
<td>108 ± 12</td>
<td>137 ± 19*</td>
<td>140 ± 11*</td>
<td>.001</td>
</tr>
<tr>
<td>Clinic DP (mm Hg)</td>
<td>61 ± 7</td>
<td>75 ± 11*</td>
<td>82 ± 9†</td>
<td>.001</td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>82 ± 8</td>
<td>103 ± 14*</td>
<td>108 ± 9*</td>
<td>.001</td>
</tr>
<tr>
<td>AMB 24 h SP (mm Hg)</td>
<td>122 ± 7</td>
<td>142 ± 13</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>AMB 24 h DP (mm Hg)</td>
<td>80 ± 6</td>
<td>97 ± 7</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>AMB daytime SP (mm Hg)</td>
<td>127 ± 6</td>
<td>145 ± 13</td>
<td>.001</td>
<td></td>
</tr>
<tr>
<td>AMB daytime DP (mm Hg)</td>
<td>83 ± 5</td>
<td>99 ± 8</td>
<td>.001</td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD.

* P < .05 v normotension.

† P < .05 v white coat hypertension.

GP: general practitioner; SP: systolic pressure; DP: diastolic pressure; MAP: mean arterial pressure; AMB: ambulatory blood pressure.

Table 2 shows the arterial pressures in the normotensive, white coat, and ambulatory groups. The values are presented as mean ± SD, with statistical significance indicated by P-values.

### Table 3. Hemodynamic Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Normotension (n = 32)</th>
<th>White Coat (n = 28)</th>
<th>Ambulatory (n = 23)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart rate (beats/min)</td>
<td>64 ± 8</td>
<td>67 ± 12</td>
<td>68 ± 6</td>
<td>.3</td>
</tr>
<tr>
<td>Aortic VTI (cm)</td>
<td>23 ± 4</td>
<td>24 ± 4</td>
<td>24 ± 4</td>
<td>.4</td>
</tr>
<tr>
<td>LVOT (cm)</td>
<td>2.34 ± 0.19</td>
<td>2.31 ± 0.21</td>
<td>2.34 ± 0.16</td>
<td>.8</td>
</tr>
<tr>
<td>SI (mL/m²)</td>
<td>52 ± 11</td>
<td>53 ± 8</td>
<td>53 ± 7</td>
<td>.9</td>
</tr>
<tr>
<td>CI (L/min/m²)</td>
<td>3.3 ± 0.8</td>
<td>3.5 ± 0.8</td>
<td>3.6 ± 0.5</td>
<td>.3</td>
</tr>
<tr>
<td>TPRI (dyne/sec/cm²/m²)</td>
<td>2059 ± 370</td>
<td>2436 ± 565*</td>
<td>2458 ± 347*</td>
<td>.001</td>
</tr>
<tr>
<td>R (dyne/sec/cm²)</td>
<td>1022 ± 206</td>
<td>1207 ± 305*</td>
<td>1186 ± 176*</td>
<td>.006</td>
</tr>
<tr>
<td>C (mL/mm Hg)</td>
<td>1.92 ± 0.51</td>
<td>1.42 ± 0.49*</td>
<td>1.57 ± 0.46*</td>
<td>.0006</td>
</tr>
<tr>
<td>Z (dyne/sec/cm²)</td>
<td>69 ± 21</td>
<td>89 ± 36*</td>
<td>81 ± 22</td>
<td>.02</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

* P < .05 v normotension.

VTE: Doppler velocity-time integral; LVOT: aortic annulus diameter; SI: stroke index; CI: cardiac index; TPRI: total peripheral resistance index; R: peripheral resistance; C: total arterial compliance; Z: aortic characteristic impedance.

Table 3 and Figure 2 show characteristics of the subjects in the white coat group with (Group A) and without (Group B) a blood pressure response during echocardiography, as defined above. While age, heart rate, and cardiac index were significantly higher, total arterial compliance was significantly lower in Group A than in Group B, but there were no differences concerning stroke index and total peripheral resistance index. Moreover, cardiac index and total peripheral resistance index were both increased in Group A compared to the normotensive group (P < .05).

To study whether there were any characteristics associated with a high ratio of vascular resistance/cardiac output and vice versa, Group A was divided into groups according to total peripheral resistance index below and above mean total peripheral resistance index ± 1 SD in the normotensive group (ie, below and above 2400 dyn/s/cm²/m²). The 10 subjects (4 men/6 women) in the low vascular resistance group were younger (45 ± 10 v 56 ± 7 years, P = .01) and had significantly increased heart rate (77 ± 11 v 63 ± 11 beats/min, P = .01), stroke index (57 ± 5 v 48 ± 9 mL/m², P = .01) and cardiac index (4.5 ± 0.6 v 3.1 ± 0.5 L/min/m², P < .0001) compared to the other group. There were no differences between these groups concerning body surface area, left ventricular mass index, ambulatory blood pressures, clinic arterial pressures, oscillatory arterial pressures, blood pressure response during echocardiography, or total arterial compliance (all P = NS).
TABLE 4. CHARACTERISTICS OF GROUPS WITH A BLOOD PRESSURE RESPONSE > 5 mm Hg (GROUP A) AND < 5 mm Hg (GROUP B)

<table>
<thead>
<tr>
<th></th>
<th>Group A</th>
<th>Group B</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender (men/women)</td>
<td>9/10</td>
<td>7/2</td>
<td>.1</td>
</tr>
<tr>
<td>Age (years)</td>
<td>51±10</td>
<td>39±14</td>
<td>.02</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.86±0.19</td>
<td>1.99±0.14</td>
<td>.08</td>
</tr>
<tr>
<td>LVMI (g/m²)</td>
<td>98±38</td>
<td>116±24</td>
<td>.3</td>
</tr>
<tr>
<td>AMB daytime SP (mm Hg)</td>
<td>126±6</td>
<td>127±9</td>
<td>.8</td>
</tr>
<tr>
<td>AMB daytime DP (mm Hg)</td>
<td>83±5</td>
<td>83±6</td>
<td>.9</td>
</tr>
<tr>
<td>Clinic SP (mm Hg)</td>
<td>147±19</td>
<td>134±14</td>
<td>.06</td>
</tr>
<tr>
<td>Clinic DP (mm Hg)</td>
<td>90±7</td>
<td>88±9</td>
<td>.5</td>
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<tr>
<td>Oscillometric SP (mm Hg)</td>
<td>146±14</td>
<td>119±12</td>
<td>.0001</td>
</tr>
<tr>
<td>Oscillometric DP (mm Hg)</td>
<td>79±7</td>
<td>68±12</td>
<td>.0001</td>
</tr>
<tr>
<td>MAP (mm Hg)</td>
<td>109±10</td>
<td>90±11</td>
<td>.0001</td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>70±13</td>
<td>60±8</td>
<td>.05</td>
</tr>
<tr>
<td>SI (mL/m²)</td>
<td>53±9</td>
<td>51±7</td>
<td>.5</td>
</tr>
<tr>
<td>CI (L/min/m²)</td>
<td>3.8±0.9</td>
<td>3.0±0.2</td>
<td>.02</td>
</tr>
<tr>
<td>TPR1 (dyne/sec/cm²/m²)</td>
<td>2463±67</td>
<td>2380±202</td>
<td>.7</td>
</tr>
<tr>
<td>R (dyne/sec/cm²)</td>
<td>1243±361</td>
<td>1133±109</td>
<td>.4</td>
</tr>
<tr>
<td>C (mL/mm Hg)</td>
<td>1.25±0.37</td>
<td>1.78±0.54</td>
<td>.005</td>
</tr>
<tr>
<td>Z (dyne/sec/cm³)</td>
<td>98±38</td>
<td>71±21</td>
<td>.06</td>
</tr>
</tbody>
</table>

Values are mean ± SD.

LVM: left ventricular mass index; AMB: ambulatory blood pressure; SP: systolic pressure; DP: diastolic pressure; MAP: mean arterial pressure; SI: stroke index; CI: cardiac index; TPR1: total peripheral resistance index; R: peripheral resistance; C: total arterial compliance; Z: aortic characteristic impedance.

DISCUSSION

A definition of white coat hypertension that assumes a completely normal cardiovascular status during everyday life may imply a lower ambulatory blood pressure cut-off than used in this study. However, since there is no general agreement on the definition of white coat hypertension, we used current procedures in this hospital for the selection of subjects with white coat hypertension, even though this may give access to subjects with borderline hypertension.

This study has shown that subjects who had an arterial systolic pressure during the echocardiographic examination that was > 5 mm Hg higher than the ambulatory daytime systolic pressure had increased vascular resistance as well as increased cardiac output compared to a normotensive control group. The subjects in this group who had an increased cardiac output / low peripheral vascular resistance pattern were younger than the subjects with the opposite pattern.

Increased sympathetic nervous system activity, which is considered to be an important pathogenetic mechanism in borderline hypertension, as well as in white coat hypertension, most appropriately explains the blood pressure response in subjects with white coat hypertension. However, the different hemodynamic patterns seen in individual subjects may indicate that activity of other neuroendocrine mechanisms, such as the renin angiotensin system and the parasympathetic system, may modulate the sympathetic activity.

Different hemodynamic patterns with advancing age may be due to an increased ratio of norepinephrine to epinephrine secretion, but a different responsiveness to catecholamines may also play a role. The tendency toward increased vascular resistance and reduced cardiac output with advancing age, regardless of underlying etiology, will tend to reinforce this hemodynamic pattern because an increased afterload is imposed on the left ventricle with diminished contractile reserve, thereby creating a vicious circle. However, to investigate whether hemodynamics associated with the white coat arterial pressure response convert from one pattern to another pattern with advancing age requires a follow-up study.

While cardiac output and peripheral vascular resistance determine the mean arterial pressure, the degree of large artery stiffness contributes to determining the arterial pulse pressure. Although arterial stiffness represents the major part of the total peripheral resistance, the resistance to pulsatile flow, determined by the large arteries, may have a relatively large impact on left ventricular function. Total arterial compliance and aortic characteristic impedance are variables that may be used to indicate the degree of large artery stiffness.

The reduced total arterial compliance associated with the white coat arterial pressure increase in this study was probably due to increased arterial distension pressure, but an additional effect induced by large artery vasoconstriction cannot be excluded. In this regard it was interesting to notice that the white coat group tended to have wider pulse pressures than
the hypertensive group for similar arterial pressure levels, not only during the echocardiographic examination, but also during the examination by the general practitioner and in the clinic. If this represents an increased large artery smooth muscle tonus, it may indicate that these subjects have an increased vascular responsiveness.

However, alternative explanations for the difference in pulse pressure between the white coat group and the hypertensive group must be considered. The possibility of a reduced elastic modulus of the arterial wall in hypertension was discussed in a recent publication. Although there is large evidence that vascular remodeling in ambulatory hypertension will tend to decrease arterial compliance by increasing vascular wall thickness, studies in animals have provided evidence for the opposite.

The clinical significance of hemodynamics in borderline hypertension has been a matter of debate for years. Although white coat hypertension may be considered a special case of borderline hypertension and may serve as a model for the understanding of the pathophysiological mechanisms of early hypertension, the results of the present study may not simply be extrapolated to borderline hypertension as traditionally defined. Moreover, since most earlier studies on hemodynamics in borderline hypertension did not use ambulatory blood pressure monitoring for the categorization of subjects, hypertension in several of these subjects may have been due to an alerting reaction, which complicates the issue considerably. However, we have shown that the evaluation of hemodynamics in hypertension with a completely noninvasive method is feasible. This method, which integrates simultaneous recordings of pressure and flow, may provide important information about the pathophysiology of hypertension and thereby contribute to the classification of subjects into groups with different disease mechanisms and possibly different prognoses.

Another important clinical implication of this study is that it may indicate that ambulatory blood pressure monitoring is required for the categorization of hypertensive subjects, since the subjects in the white coat group showed a pronounced white coat arterial blood pressure response even by the careful measurements of arterial pressures performed by a nurse and under the quiet circumstances during echocardiography.

**CONCLUSION**

The blood pressure response in subjects with white coat hypertension is associated with increased cardiac output, increased peripheral vascular resistance, and reduced total arterial compliance, but the hemodynamic pattern may be influenced by age. The reduced total arterial compliance is probably a consequence of passive distension of the arterial wall, but an increased large artery smooth muscle tonus cannot be excluded.

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**REFERENCES**


