Exercise blood pressure and baroreflex function in borderline hypertensive and normotensive young men

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Summary
1. Resting carotid baroreflex sensitivity and blood pressure responses to standardized conditions of rest and exercise were measured in 17 borderline hypertensive males and 12 normotensive males.

2. The borderline hypertensive group had significantly higher systolic and diastolic blood pressures during orthostatic rest and isometric handgrip exercise and higher systolic blood pressure during supine rest and submaximum and maximum treadmill exercise.

3. The borderline hypertensive group had an attenuation of baroreflex sensitivity compared with the normotensive group. Resting baroreflex sensitivity was significantly correlated with absolute systolic blood pressure during supine rest, orthostatic rest, isometric handgrip exercise and submaximum and maximum treadmill exercise.

4. The results indicate that blood pressure is regulated at a significantly higher level during rest and exercise in borderline hypertension and is associated with reduced baroreflex sensitivity measured at supine rest.

Key words: borderline hypertension, carotid baroreflex, exercise.

Abbreviations: BP, blood pressure (DBP, SBP, diastolic, systolic); HR, heart rate.

Introduction
Borderline hypertension is characterized by resting blood pressure in the range 140/90 to 150/100 mmHg [1] and increased blood pressure during various physical stresses such as orthostatic tilt [2], isometric exercise [3-5] and dynamic exercise [6-9] compared with normal subjects. Recent studies have indicated that exercise blood pressure responses may be helpful in the early diagnosis of borderline hypertension [10-12].

Altered baroreflex function has been reported in borderline and established hypertension. These changes include increased baroreflex 'set point' and decreased sensitivity [13-17]. These reflexes normally become less sensitive during physical exercise [18-20]. Accordingly, attenuated baseline baroreflex sensitivity may further affect the magnitude of blood pressure responses to exercise in hypertensive patients.

To clarify the potential role of altered baroreceptor reflex in blood pressure regulation we measured resting carotid baroreflex function and blood pressure responses to rest and exercise conditions in borderline hypertensive and normotensive young men.

Methods and materials

Subjects
Patients with suspected borderline hypertension (n = 17) were referred from the University of Wisconsin Health Service hypertension clinic. These patients had shown variable or persistent elevation of resting blood pressure (BP) ranging from 140/90 to 155/100 mmHg, with occasional
normal values during a 7-10 day screening period. Routine clinic evaluation included standardized history, physical examination, chest roentgenogram, resting ECG and laboratory studies of serum electrolytes, blood urea nitrogen, creatinine, 24 h urine creatinine and sodium excretion. No cases of secondary hypertension were detected. Borderline hypertensive subjects had not received antihypertensive drug treatment before or at the time of the study.

Control subjects (n = 12) were recruited from scheduled physical education classes. They were screened with history, physical examination and blood pressure readings recorded for a period of 4-6 days. Control subjects were excluded if they had a history of prior borderline hypertension or current resting BP values exceeding 140/90 mmHg. All subjects agreed to participate in these studies by informed consent approved by the Committee for Human Subjects, University of Wisconsin Center for Health Sciences.

Protocol

Two experimental sessions were scheduled for each subject within the course of a 1 week period. All testing was done between 07.00 and 10.00 hours before exercise and stimulants. At the initial session we measured height and weight and percentage of body fat [21]. Heart rate (HR) and BP responses were then measured during four standardized conditions.

1. Supine rest. Subjects lay on a tilt table in the horizontal position in a quiet room for 20 min. BP and HR were obtained each 5 min. The values at 20 min were chosen for supine rest BP and HR.

2. Orthostatic stress. The subjects were passively tilted to 70° head-up position. BP and HR were measured each minute for 5 min. The values at the fifth minute were used for orthostatic BP and HR.

3. Isometric handgrip. Maximum handgrip tension was determined from the average of two voluntary contractions of a hand dynamometer (Stoelting), the right hand being used. Subjects then held the dynamometer at 50% maximum grip tension for 90 s. BP and HR were measured in the opposite arm each 30 s. The values at 90 s were used for maximum isometric BP and HR.

4. Treadmill exercise. BP was measured each minute during a walking treadmill protocol, in which treadmill speed was held constant (3.3-3.9 mph) and grade was increased 2.5% each 2 min until 10 min and then 2.0% each 2 min thereafter. ECG was monitored continuously in bipolar lead CM5. End point for the test was subjective exhaustion. Maximum exercise capacity was calculated from treadmill speed and grade and expressed in MET units (1 MET is defined as the metabolic cost of rest and has a value of 3.5 ml of O2 min⁻¹ kg⁻¹ [22]). BP and HR values at 25, 50, 75 and 100% of maximum MET capacity were selected for this study so that BP responses could be compared as a function of relative exercise capacity for each subject.

Blood pressure measurement

Brachial artery BP was measured by auscultation with a binaural stethoscope with extended (60 cm) conducting tube and anaesthesia diaphragm, which was secured by an elastic Velcro strap to the antecubital surface. Auscultatory pressures were determined according to American Heart Association Guidelines, using a standard mercury manometer mounted at eye level to avoid parallax [23]. The appropriate cuff was used, based on size of the arm. Systolic pressure (SBP) was recorded as the first of successive audible sounds and phase 5 was accepted as diastolic pressure (DBP) for supine rest, standing rest and isometric exercise.

Validation of exercise BP measurement technique was determined in two parallel studies. First, exercise auscultatory BP values were compared with simultaneous brachial intra-arterial pressure measurements in normal volunteers during isometric handgrip and treadmill exercise identical

<table>
<thead>
<tr>
<th>Exercise mode</th>
<th>Isometric handgrip</th>
<th>Treadmill exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systolic</td>
<td>Diastolic</td>
<td>Systolic</td>
</tr>
<tr>
<td>No. of observations</td>
<td>30</td>
<td>29</td>
</tr>
<tr>
<td>Correlation coefficient</td>
<td>0.88</td>
<td>0.81</td>
</tr>
<tr>
<td>Standard error of estimate</td>
<td>±8.5</td>
<td>±7.3</td>
</tr>
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</table>
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with the study protocol. The results of these studies are summarized in Table 1. Systolic pressure values for auscultation were closely correlated with direct arterial pressure during isometric handgrip \((r = 0.88)\) and treadmill exercise \((r = 0.94)\). Diastolic pressure during auscultation was satisfactory in isometric handgrip \((r = 0.80)\) but weakly correlated during treadmill exercise \((r = -0.34)\).

In a second study we evaluated the reproducibility of BP responses in a subgroup of 12 borderline hypertensive subjects \([24]\). Each subject was tested and retested within a 10 day period, the identical protocol described for this study being used. The results are presented as the mean differences and correlation coefficients between test and retest BP values for each condition of the protocol (Table 2). There was close agreement with initial test versus retest SBP, DBP and HR values for supine rest, orthostatic rest and isometric handgrip. During treadmill exercise, values were compared at 25, 50, 75 and 100% of relative effort. There were significant differences found for SBP at 50% max. and DBP at 100% max. However, the absolute values of the differences were small.

Because DBP measured by auscultation was inaccurate during treadmill exercise we have limited that portion of our study to evaluation of SBP responses.

Baroreflex function

During the second experimental session resting carotid baroreflex sensitivity was assessed in the supine position by HR response to graded neck suction using a method previously described by Eckberg et al. \([25]\). Briefly, the carotid baroreflex was stimulated by applying suction at pressures of \(-20, -30, 40\) mmHg for 0.6 s to a neck chamber constructed from sheet lead rimmed with rubber padding. All suckings were applied during held expiration to control HR and were timed to begin 0.7–0.8 s before the next expected P wave. The intensity of suction was regulated by a rheostat and solenoid valve system and monitored with a strain gauge pressure transducer mounted on the chamber. A computer controlled the onset of suction and its duration. Six stimuli at each pressure intensity were delivered randomly. ECG lead II and suction pressure were recorded on a Gilson recorder (model 5/6). The longest ECG R–R interval after the onset of suction was used as the bradycardia response. The prolongation of the R–R interval from the last interval before suction was plotted as a function of stimulus intensity. Baroreflex sensitivity was defined as the slope of this relationship.

Data analysis

Statistical analyses were performed with a Sperry-Univac 1100 digital computer. Two sample \(t\)-tests for paired and unpaired data were used when appropriate. Analysis of variance with repeated measures was used in comparing resting and treadmill BP. Pearson-product moment correlation analysis was used to evaluate relationships between baroreflex sensitivity and BP data. Subsequent data are presented as the means and standard deviations of the mean unless otherwise specified. Statistical significance was accepted at \(\alpha < 0.05\).

Table 2. Reproducibility of blood pressure response to treadmill exercise in borderline hypertensive subjects \((n = 12)\)

<table>
<thead>
<tr>
<th>HR (min⁻¹)</th>
<th>SBP (mmHg)</th>
<th>DBP (mmHg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Δ ± SD</td>
<td>r</td>
</tr>
<tr>
<td>Supine rest</td>
<td>0 ± 7</td>
<td>0.76</td>
</tr>
<tr>
<td>Orthostatic rest</td>
<td>2 ± 11</td>
<td>0.63</td>
</tr>
<tr>
<td>Isometric grip</td>
<td>-2 ± 11</td>
<td>0.55</td>
</tr>
<tr>
<td>Treadmill exercise</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25% max.</td>
<td>5 ± 11</td>
<td>0.71</td>
</tr>
<tr>
<td>50% max.</td>
<td>4 ± 12</td>
<td>0.61</td>
</tr>
<tr>
<td>75% max.</td>
<td>0 ± 8</td>
<td>0.83</td>
</tr>
<tr>
<td>100% max.</td>
<td>0 ± 3</td>
<td>0.95</td>
</tr>
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Results

Subject characteristics (Table 3)

Both subject groups were closely matched for physical characteristics. There were no significant differences in age, body weight, percentage of body fat, or maximum heart rates between the groups. However, the normal subjects were significantly taller and had a greater treadmill exercise capacity.

Blood pressure responses (Fig. 1)

During the 20 min of supine rest, the BP declined by 4–12 mmHg in each group. Both SBP
and DBP were significantly higher in the borderline hypertensive subjects (128 ± 9/78 ± 8 mmHg) compared with control subjects (119 ± 8/71 ± 7 mmHg). During 5 min of 70° tilting, both SBP and DBP remained significantly higher ($P < 0.05$) in the borderline hypertensive group (132 ± 12/95 ± 5) compared with the control group (118 ± 7/80 ± 5).

Both groups demonstrated the typical pressor response during 90 s of isometric handgrip exercise. However, the absolute value of both SBP and DBP was significantly ($P < 0.01$) greater for the borderline hypertensive subjects (176 ± 14/127 ± 10) than for the control subjects (154 ± 16/112 ± 11).

During treadmill exercise, both groups showed the expected pattern of increase in SBP. The borderline hypertensive subjects had significantly higher absolute SBP measured at 25, 50, 75 and 100% of maximum work capacity.

Relative changes in blood pressure (Fig. 2)

The relative changes in SBP calculated as the increase or decrease from supine rest are shown in Fig. 2. The borderline hypertensive group exhibited a greater increase in SBP during all conditions. However, the magnitude of change of SBP during orthostatic stress and isometric handgrip in the borderline hypertensive group was not significantly different from in the control group. The magnitude of changes in DBP during these two conditions, although not shown, were also similar in the two groups.

During treadmill exercise, the relative increase in SBP from supine rest was significantly higher in the borderline hypertensive subjects at 25% and 50% of maximum treadmill exercise. However, the increases in SBP at 75% and 100% maximum treadmill exercise capacity were not significantly different between groups.

Baroreflex responses (Fig. 3)

Differences in baroreflex responses between the borderline hypertensive subjects and the controls were analysed in three ways. First, baroreflex responses at each level of neck suction were compared. The mean values at each subatmospheric pressure were lower in the borderline hypertensive group, but these differences were not significant. Secondly, baroreflex sensitivity was compared in the two groups by trend analysis utilizing repeated measures. This analysis indicated that the attenuation of baroreflex sensitivity in the borderline hypertensive group compared with the control group was significant ($P < 0.05$). Thirdly,
baroreflex 'resetting' was evaluated by comparing the intercept values for the baroreflex sensitivity slopes for the borderline hypertensive and control groups. No significant difference was found between the two groups.

Correlational analysis was used to compare baroreflex sensitivity and SBP during rest and exercise conditions (Table 4). Baroreflex sensitivity was inversely correlated with SBP during supine rest \((r = -0.41)\). The correlations between baroreflex sensitivity and SBP during orthostatic stress, isometric handgrip exercise and 25% maximum treadmill exercise were somewhat stronger \((r = -0.55, -0.61 \text{ and } -0.57 \text{ respectively})\). Thus baroreflex sensitivity accounted for 30-37% of the variation in SBP during these conditions.

**Discussion**

**Blood pressure responses**

Previous studies in patients with borderline hypertension have shown that these patients exhibit higher BP values compared with normotensive controls during isometric and dynamic exercise \([3-9]\). Controversy exists, however, on whether the BP response is greater in these patients or merely increases equally from a higher resting BP. Our data are in agreement with previous studies which report similar responses to orthostatic stress, isometric handgrip exercise and maximum treadmill exercise in borderline hypertensive and in normotensive subjects. However, our data indicate that SBP response to submaximum (25% and 50%) is significantly greater in the borderline hypertensive group.

Elevated BP values during exercise in borderline hypertensive patients have been attributed to inappropriately higher peripheral resistance coupled to normal increases in cardiac output [6, 7]. The significantly greater increases in SBP during submaximum (25% and 50%) exercise in borderline hypertensive subjects in the present study indirectly suggest that the mismatch between cardiac output and peripheral resistance may be greater during early phases of dynamic exercise.

Most studies have evaluated the BP response to dynamic exercise at maximum capacity or at the same absolute submaximum workload and have not accounted for differences in maximum working capacity between subjects. Expressing BP data as a function of relative exercise intensity provides a method of comparing different groups at similar levels of stress. Henquet et al. [26] reported BP values in borderline hypertensive subjects during 50% and 75% submaximum and maximum cycle ergometer exercise which are remarkably similar to our treadmill data.

**Baroreflex responses**

We postulated that borderline hypertensive subjects with attenuated baroreceptor sensitivity at rest would also have hypertensive BP regulation during exercise. Previously, Mancia et al. demonstrated that baroreflex HR responses determined during isometric exercise may be impaired while corresponding BP responses remain unchanged [18, 27]. Accordingly, we elected to measure resting baroreflex activity to determine the possible role of altered baroreflex sensitivity in regulation of BP during exercise.

Sleight et al. [28] found a strong relationship between mean arterial BP achieved during submaximum upright bicycle exercise and resting baroreflex sensitivity determined by phenylephrine injection. In contrast, Mancia et al. [29] reported no correlation between ambulatory BP variability and baroreflex sensitivity obtained by neck suction. The borderline hypertensive subjects in the present study demonstrated a significant trend toward attenuation of resting baroreflex sensitivity. The BP values during orthostatic stress, isometric exercise and treadmill exercise were all significantly correlated with resting baroreflex sensitivity. These correlations suggest that the resting baroreflexes are partially predictive of BP during exercise.

The minimal attenuation of baroreflex sensitivity demonstrated in this study may be related to the level of resting BP in our borderline hypertensive group. Eckberg [14] described a gradation of baroreflex responsiveness among patients classified as normal or having mild to moderate hypertension. He found attenuated baroreflex responsiveness only in subjects whose resting SBP

**TABLE 4. Correlations between baroreflex sensitivity and systolic blood pressure during rest and exercise**

<table>
<thead>
<tr>
<th>Condition</th>
<th>( r )</th>
<th>( P )</th>
</tr>
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<tbody>
<tr>
<td>Supine rest</td>
<td>-0.41</td>
<td>0.03</td>
</tr>
<tr>
<td>Orthostatic rest</td>
<td>-0.54</td>
<td>0.004</td>
</tr>
<tr>
<td>Isometric grip</td>
<td>-0.61</td>
<td>0.001</td>
</tr>
<tr>
<td>Treadmill exercise 25% max.</td>
<td>-0.57</td>
<td>0.003</td>
</tr>
<tr>
<td>50% max.</td>
<td>-0.42</td>
<td>0.025</td>
</tr>
<tr>
<td>75% max.</td>
<td>-0.35</td>
<td>NS</td>
</tr>
<tr>
<td>100% max.</td>
<td>-0.41</td>
<td>0.04</td>
</tr>
</tbody>
</table>

\( P \), Statistical significance of unpaired \( t \)-test; NS, not significant.
was greater than 140 mmHg. Although our subjects had clinical evidence of borderline hypertension, they had minimal increases in resting supine SBP (129 ±8 mmHg) and showed only small changes in baroreflex sensitivity similar to Eckberg's borderline hypertensive subjects, with mild elevation of resting SBP (134 mmHg).

Carotid baroreflex responses measured in the supine position may not reflect overall baroreflex control of BP in the upright position in borderline hypertensive subjects. Mark & Kerber [30] have shown that the BP responses to supine and orthostatic position change in these subjects may be strongly influenced by enhanced cardiopulmonary baroreceptor activity. These low pressure afferent receptors normally exert additional reflex inhibitory influences on peripheral resistance and BP. In borderline hypertensive patients with attenuated carotid baroreflex sensitivity cardiopulmonary activity is enhanced and acts to control BP in the supine position. Accordingly, an exaggerated increase in BP occurs when changing from the supine to the upright position. The magnitude of the BP response to upright exercise is then determined by the prevailing level of carotid-aortic baroreceptor sensitivity.

Eckberg et al. [31] evaluated the effect of posture on carotid baroreflex responsiveness in 12 normotensive men by using graded neck suction. They found that upright posture did not modify baroreflex pulse interval responses compared with the supine position. We also studied the effect of upright posture on baroreflex responsiveness in a subgroup of normotensive and borderline hypertensive subjects similar to those in the present study. The responsiveness in the 70° upright tilt position was not significantly different from that in the supine position in either group of subjects (unpublished observations). Thus, baroreflex responses measured in the supine position provide a satisfactory estimate of baroreflex responsiveness in the upright position in these subjects.

In conclusion, our results suggest that BP is regulated at a higher level during supine rest, orthostatic rest, isometric handgrip, and submaximum and maximum treadmill exercise in borderline hypertensive men. A significant trend toward attenuation of resting baroreceptor sensitivity is also present in borderline hypertensive subjects. We also found significant inverse relationships between baroreceptor sensitivity and SBP during orthostatic stress, isometric exercise and submaximum treadmill exercise. Thus, altered baroreceptor sensitivity may determine in part the magnitude of BP response to exercise in borderline hypertension.

Acknowledgments

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References