Influence of Hypertension on the Hemodynamic Response to Exercise

By Antoon Amery, M.D., Stevo Julius, M.D., Sc.D., Leigh S. Whitlock, Ph.D., and James Conway, M.D., Ph.D.

SUMMARY

Sixty-one asymptomatic hypertensive patients from 19 to 68 years of age were subjected to a progressive exercise test on a cycle ergometer. A decline in maximal oxygen consumption and cardiac output and an increase in systolic blood pressure were observed with age. These findings were similar to those observed in normal subjects. In the middle-aged (35 to 49 years) and older subjects (50 to 60 years), the systolic pressure showed a greater increase with exercise than in normals of their age, but this did not apply to subjects aged 19 to 34 years. The cardiac response to exercise was normal at rest and at all levels of exercise in the middle-aged group, but the oldest group showed a reduced maximum cardiac output. In the youngest age group, cardiac output was normal at rest but fell below normal at all levels of exercise.

Maximal voluntary oxygen consumption and cardiac output were significantly reduced with increasing severity of hypertension.

Additional Indexing Words:
Aging Cardiac output Peripheral resistance
Arterial blood pressure Oxygen consumption

Hypertension is a disorder affecting the normal regulation of blood pressure, and under the stress of exercise there is a greater rise in arterial pressure in hypertensive than in normal subjects. In this study, the extent of this rise in a large number of hypertensive patients has been investigated to determine whether this response is sufficiently characteristic for this condition to be used as a diagnostic test in doubtful cases. Since hypertension presents an excessive work load on the heart, and most patients lead a normally active life, emphasis has also been placed upon the cardiac response to exercise.

Selection of Patients

Sixty-one patients with hypertension (44 males and 17 females) from 19 to 68 years of age were studied. Persistent elevation in diastolic pressure was a requirement for inclusion of a patient in this study; all readings in the recent past were 90 mm Hg or more and at least five measurements, on separate days, were made. Since it was desirable to separate the effects of hypertension from its cardiovascular consequences, no one who had complained of cardiac symptoms or had a history of a heart attack was included. Furthermore, no subject had electrocardiographic evidence suggestive of an earlier myocardial infarction. Only patients who were carrying on their usual occupations were accepted. Information gained from a questionnaire regarding the usual activities of this group of patients showed that they did not differ from those of the normal subjects with whom they were compared. Almost all subjects were engaged in sedentary occupations and, with few exceptions, undertook no strenuous physical exertion. An estimation of arterial disease in each patient was made from physical examination (absent arterial pulses or vascular murmurs), x-ray evidence (unfolding of the aorta), and determination of the serum cholesterol.

The data on these patients were compared with those in the 54 normal subjects in the previous publication, and as in that study, the patients were divided into three groups according...
to age: group I comprised 13 subjects aged 19 to 34 years; group II, 25 subjects aged 35 to 49 years; and group III, 23 subjects aged 50 to 69 years. The sex distribution in these groups was essentially similar to that in the normal subjects. Patients with both primary and secondary hypertension were included in the analysis by age. There were six patients with renovascular disease, three with parenchymal renal disease, and five with primary aldosteronism. The number of patients with secondary hypertension is quite small, and only in group I did they contribute significantly to the total. The responses of these subjects will be considered in relation to the behavior of their age groups as a whole.

Methods

All patients undertook the progressive exercise test precisely as described in the preceding paper. In 20 of the 61 patients, however, the cardiac output was not determined since the necessary apparatus was not available at the time or failed to operate satisfactorily. Nevertheless, they have been included because the intra-arterial blood pressure measurements are of value for the purpose of this study. In tables 1 and 2, therefore, the numbers for whom cardiac output data were available are given. In 35 patients, the vital capacity was measured before and after exercise and in 12, the partial pressure of oxygen (Pao2), of carbon dioxide (Paco2), and the pH in arterial blood were also measured.

Results

Analysis of the data for hypertensive patients is considered in the same manner as the analysis of the normal subjects; maximal response to exercise is first followed by an analysis of their responses according to increments in oxygen consumption. Finally, the severity and clinical types are considered.

Findings at Maximally Achieved Level of Exercise

The maximum voluntary exercise capacity of the hypertensive subjects grouped according to age is given in table 1. This shows that the maximum level of oxygen consumption and cardiac output achieved by the hypertensive patients fell with age very much as it did in the normals and compared with the respective normal groups, the oxygen consumption (Vo2) in the hypertensive subjects was not significantly lower than in the normal. The maximum heart rate was the same as that of the normal for each group, as was the respiratory exchange ratio, from which it may be inferred

![Figure 1](image-url)
Table 1
Mean ± Standard Error of Cardiopulmonary Data at the Voluntary Maximal Exercise Level in Sixty-one Hypertensive Subjects Grouped According to Age

<table>
<thead>
<tr>
<th>Age group</th>
<th>BSA (m²)</th>
<th>$\dot{V}_{O_2}$ (ml/min)</th>
<th>$\dot{V}_1$ (L/min)</th>
<th>R</th>
<th>Pulse rate (beats/min)</th>
<th>Arterial blood pressure (mm Hg)</th>
<th>Cardiac output (L/min)</th>
<th>Total peripheral resistance (dynes sec cm⁻²)</th>
<th>$O_2$ difference (ml/100 ml)</th>
<th>Calculated</th>
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<tbody>
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<td>Group I</td>
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<tr>
<td>2.15</td>
<td>1843.3</td>
<td>41.0</td>
<td>1.05</td>
<td></td>
<td>166.8</td>
<td>234.0*** 128.4*** 162.5***</td>
<td>12.39*</td>
<td>1017.5***</td>
<td>13.7</td>
<td></td>
</tr>
<tr>
<td>±0.04</td>
<td>±87.4</td>
<td>±2.55</td>
<td>±0.013</td>
<td></td>
<td>±6.0</td>
<td>±7.23  ±4.08  ±4.30</td>
<td>±0.866</td>
<td>±88.12</td>
<td>±0.68</td>
<td>N = 12</td>
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<tr>
<td>Group II</td>
<td></td>
<td></td>
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<tr>
<td>2.10</td>
<td>1550.3</td>
<td>38.4</td>
<td>1.04</td>
<td></td>
<td>151.7</td>
<td>258.5*** 135.2*** 177.3***</td>
<td>14.43</td>
<td>999.5***</td>
<td>11.6</td>
<td></td>
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<tr>
<td>±0.08</td>
<td>±95.9</td>
<td>±2.32</td>
<td>±0.027</td>
<td></td>
<td>±4.0</td>
<td>±8.15  ±3.69  ±4.92</td>
<td>±0.762</td>
<td>±60.34</td>
<td>±0.69</td>
<td>N = 16</td>
</tr>
<tr>
<td>Group III</td>
<td></td>
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<tr>
<td>2.07</td>
<td>1191.6</td>
<td>33.2</td>
<td>1.08</td>
<td></td>
<td>145.3</td>
<td>260.2*** 130.7*** 180.2***</td>
<td>11.50</td>
<td>1344.9**</td>
<td>10.3</td>
<td></td>
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<tr>
<td>±0.06</td>
<td>±87.4</td>
<td>±3.15</td>
<td>±0.025</td>
<td></td>
<td>±3.8</td>
<td>±5.78  ±3.08  ±4.02</td>
<td>±0.822</td>
<td>±93.3</td>
<td>±0.90</td>
<td>N = 13</td>
</tr>
</tbody>
</table>

* to *** Significance values refer to differences from the corresponding age group of the normals (in the previous paper.) *P < 0.05 **P < 0.01 ***P < 0.001.

Abbreviations: BSA = body surface area in square meters; $\dot{V}_{O_2}$ = oxygen consumption; $\dot{V}_1$ = volume of inspired air; R = respiratory exchange ratio; and N = the number of subjects in each group for whom cardiac output data were obtained.
Table 2
Mean ± Standard Error of the Hemodynamic Data on Hypertensive Subjects Grouped According to Severity*

<table>
<thead>
<tr>
<th>Resting recumbent diastolic pressure (mm Hg)</th>
<th>N†</th>
<th>Age (yr)</th>
<th>Resting $\dot{V}_{O_2}$ (ml/min)</th>
<th>Sitting cardiac output (L/min)</th>
<th>Stroke volume (ml/beat)</th>
<th>At maximum voluntary exercise</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-99</td>
<td>20/12</td>
<td>46 ± 2.1</td>
<td>300 ± 28.6 5 ± 0.29 ± 4.5</td>
<td>75 ± 4.1</td>
<td>1614 ± 16 ± 111</td>
<td>1614 ± 16 ± 111</td>
</tr>
<tr>
<td>99-109</td>
<td>22/15</td>
<td>42 ± 2.9</td>
<td>321 ± 28.2 5 ± 0.30 ± 4.4</td>
<td>61 ± 4.4</td>
<td>1529 ± 12 ± 83</td>
<td>1529 ± 12 ± 83</td>
</tr>
<tr>
<td>110 &amp; over</td>
<td>19/12</td>
<td>42 ± 2.07</td>
<td>297 ± 15.8 5 ± 0.36 ± 4.1</td>
<td>598 ± 4.1</td>
<td>1321 ± 12 ± 84</td>
<td>1321 ± 12 ± 84</td>
</tr>
</tbody>
</table>

*Severity has been taken as the level of the recumbent diastolic pressure at the time of the test.
†The first number refers to the total number of patients within each group and the second one to those with cardiac output measurements.
‡ and § indicate significant difference from the lowest blood pressure group. † = P < 0.05. § = P < 0.01.

Figure 2
Effect of exercise on cardiac output in normal subjects and hypertensive patients in age group II.

that the degree of motivation was probably similar to that of the normal group.

No subject showed a fall in vital capacity or in arterial oxygen saturation with exercise. The changes in $P_{aCO_2}$ and pH were practically the same as those seen in the normal group.

Observations According to the Levels of Oxygen Consumption

In the analysis of the data from hypertensive patients, it became apparent that their responses were more complex than those of normal subjects. As will be seen, this resulted from the interaction between the effects of aging and the severity of hypertension.

The changes in diastolic pressure with exercise were small and did not differ from the normal. The systolic pressure in groups II and III showed a greater rise than the normals; in the youngest age group, the change in systolic pressure was not greater than that seen in the normal subjects of the same age (fig. 1). In none of the hypertensive subjects was it possible to relate the change
in the systolic pressure with exercise to clinical or radiological evidence of atherosclerosis or to duration of the disease.

Analysis of the other hemodynamic data showed that the departures from the normal differ according to the age groups. Group II, therefore, is used for the main comparison with normals of the same age, and results for the other age group are presented only insofar as they differ from those for group II. For each parameter (figs. 2 to 5), mean data were given for the values obtained in the resting, recumbent, and sitting positions before the exercise test commenced. Thereafter, curves were constructed from the data to give mean curves according to increments of oxygen consumption during exercise.

Pulmonary ventilation and pulse rate were almost identical with the normals and are not illustrated. The curve for cardiac output (fig. 2) and that for stroke volume were almost identical with those obtained in the normal subjects. The curve for calculated arteriovenous oxygen difference was also the same (fig. 3) as the normal.

In spite of the increased work load imposed on the left ventricle by hypertension, the cardiac response to exercise in this age group was adequate. The increased cardiac work was not great enough to affect oxygen consumption for a given work load in hypertensives.

The total peripheral resistance measurements (fig. 4) showed that the hypertensive group maintained a higher resistance at all levels of exercise. Although there was some narrowing of the difference between the normal and hypertensive groups at the lowest level of exercise, the curves soon become parallel. This pattern was the same in comparisons of all hypertensive and normal groups of the same age.

It is convenient next to consider age group III since this group showed few differences from the normals of their own age. The level of blood pressure in group III was approximately the same as for group II. The mean

![Figure 4](http://circ.ahajournals.org/)

*Effect of exercise on the total peripheral resistance in normal subjects and hypertensive patients in age group II. ** and *** indicate significant differences, ***P < 0.001; **P < 0.01.*

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![Figure 5](http://circ.ahajournals.org/)

*Effect of exercise on the cardiac output in normal subjects and hypertensive patients in age group I. * indicates significant differences, P < 0.05.*
recumbent blood pressure for the group was 185/101 mm Hg as opposed to 181/106 mm Hg for group II. The cardiac output, at rest, was lower than that of group II, but corresponded to the normal level at that age. The cardiac output at the lower levels of exercise was almost identical to that of normal subjects, but with increasing exercise, it was a little lower, and this was reflected in the lower maximum cardiac output (table 1).

For age group I, the mean resting blood pressure was 172/106 mm Hg. The cardiac output was normal at rest, both in the recumbent and sitting positions, but the increase in cardiac output with exercise was less than in the normals and, as the maximum level of exercise was reached, the cardiac output failed to increase in spite of the increasing oxygen uptake (fig. 5).

**Analysis of Results According to Severity of Hypertension**

When the data for hypertensive patients were subdivided according to the severity of the disease, as indicated by the level of the initial resting recumbent diastolic pressure, it became evident that cardiac performance was clearly affected by increased blood pressure levels. The mean cardiac output at rest, both recumbent and sitting, was the same at all levels of severity. The maximum \( V_{O_2} \), cardiac output, and stroke volume, however, was significantly lower in subjects with the most severe hypertension (table 2). The group with intermediate severity showed similar changes though the reduction in maximal oxygen consumption was not significant.

Electrocardiographic abnormalities occurred with a little greater frequency than in the normal subjects. In six patients (one in group I, two in group II, and three in group III), ventricular extrasystoles emerged during exercise, but in none of these were they sufficiently frequent to require termination of the test. Eight patients showed junctional S-T depression (two in group I, three in group II, and three in group III); six patients showed ischemic depression of the S-T segment (one in group I, two in group II, and three in group III). None of the changes was reflected in observable abnormalities in the hemodynamic findings.

**Secondary Hypertension**

Neither the renal nor the adrenal types of hypertension showed differences in cardiac output at rest, nor in the patterns of response of the blood pressure and cardiac output to exercise. The number of patients involved, however, is too small to provide a firm opinion on these findings.

**Discussion**

In general, hypertensive patients demonstrated a greater rise in systolic pressure with exercise than normal subjects of the same age,1-3 but in the youngest group this was not apparent. The response, therefore, was not sufficiently characteristic to be used as a test for hypertensive disease. Sannerstedt,4 likewise, found a normal rise in blood pressure with exercise in his mildest hypertensive subjects. They also formed his youngest group. The greater rise in systolic blood pressure seen in the hypertensive patients of groups II and III probably result from sclerosis of the large blood vessels as a result of the disease.5 The level of pressure itself appears to play little part since it was not observed in the youngest subjects. An excessive rise in systolic pressure during exercise has also been seen in patients with coronary artery disease.6

In all age groups, the resting cardiac output was normal; the pattern of response to exercise up to the maximum level was usually similar to the normal, indicating that the left ventricle can readily accept the increased work load until hypertension becomes severe. The youngest age group, however, showed an inadequate cardiac response indicative of the fact that, for their age, the level of hypertension represented a clinically more severe form of the disease. These findings are in general agreement with others,1,3,7 except that elevated cardiac output at rest in mild hypertension has frequently been reported.2,3,7,8 This difference may be the result of the selection of cases since the patients

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admitted to the present study were required to have sustained elevation in recumbent blood pressure. Similarly, the more severe hypertensive patients in our study did not have a lower resting cardiac output, as reported by others; here again, selection was important since subjects with symptoms indicative of cardiac failure were rejected for these experiments. It is interesting that, in spite of the absence of symptoms in our subjects, those with more severe hypertension showed a clear limitation in exercise capacity and in the maximal cardiac response to exercise. Hypertension, therefore, in all but its mildest forms offers a significant handicap to physical exercise.

It has long been recognized that the peripheral vasculature in hypertension is capable of considerable vasoconstriction and vasodilatation, and the response to exercise demonstrated that the ability to reduce the overall resistance is normal in hypertension. In general, however, as others have also observed, the difference in total peripheral resistance between the normal and hypertensive was maintained. This may represent a residual level of resistance in hypertensive blood vessels which cannot be overcome by potent vasodilator stimuli or it may indicate that the vascular beds most affected in hypertension do not take part in the vasodilatation of exercise. This would be consistent with the observation that the vascular resistance in the vessels supplying limb muscle is normal, particularly in the less severe forms of hypertension, whereas the renal and cutaneous vascular beds are greatly affected.

References
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