Hypotension Accompanying the Onset of Exertional Angina
A Sign of Severe Compromise of Left Ventricular Blood Supply

By Pate D. Thomson, M.D., and Michael H. Kelemen, M.D.

SUMMARY
Serious obstructive coronary artery disease was found in all patients who developed hypotension accompanying the onset of angina during multistage exercise testing. Seventeen exercising patients demonstrated a fall in systolic pressure to below resting levels as chest pain and ST-segment depression appeared. Two patients died suddenly six weeks after treadmill testing and prior to arteriography. The remaining fifteen were studied with coronary arteriography and all except one exhibited ≥ 90% stenosis of the left anterior descending artery (LAD). The remaining patient demonstrated two 75% LAD stenoses in series. Five exhibited significant (≥ 75%) narrowing of the main left coronary artery (MLCA) and thirteen of fifteen had significant stenosis of proximal LAD and circumflex arteries. The two patients without significant circumflex disease exhibited ≥ 90% stenosis of the dominant right coronary artery (RCA) circulation. Six of six patients had restoration of a normal blood pressure response following coronary bypass surgery, which also relieved angina and reversed ST-segment depression.

Conditions essential for proper interpretation of this sign are discussed. If these conditions are met, then a fall in systolic pressure during treadmill-induced angina pectoris is a reliable sign of severe compromise of left ventricular blood supply.

Additional Indexing Words:
Treadmill exercise testing  Coronary artery disease  Coronary arteriography

ONE OF THE MOST DIFFICULT PROBLEMS facing the clinician is identifying those patients who are at greatest risk of morbidity and mortality from coronary artery disease (CAD) and distinguishing them from the much larger pool of individuals who have signs and symptoms of CAD. Usual methods of evaluating these patients, including history, physical examination, resting ECG and exercise testing have shown only poor to fair correlation with the extent and severity of coronary vessel obstruction, yet there is good evidence that mortality does relate to the number of coronary arteries involved.1,2 Thus, many patients at risk from severe three-vessel disease present to the clinician with modest complaints regarding their angina, a normal physical examination and ECG, modest restriction in treadmill exercise capacity and little or no ST-segment depression. A reliable and easily obtained sign of severe multiple vessel coronary artery disease would be of obvious importance in determining the patient who is at higher risk from his disease, and in whom there is some urgency in initiating therapy. The occurrence of hypotension developing during exercise-induced angina pectoris is, we believe, such a sign.

The usual response to spontaneous angina is a rise in blood pressure.3,4 The usual response to exercise is also a rise in systolic blood pressure and the majority of patients with angina exhibit such a rise.5,6 A small but significant number of patients undergoing treadmill exercise develop hypotension concurrent with the appearance of ST-segment depression and symptomatic angina. Recognition of this hypotension is important not only for the safe conduct of the exercise test, but for the longer term prognosis of the patient. The value of the sign as a predictor of critical coronary artery narrowing is the subject of this report.

Methods
Seventeen patients developed hypotension during treadmill exercise-induced angina pectoris. Hypotension was defined as a fall in systolic pressure to below resting levels. Routine histories, physical examinations, chest X-rays, and electrocardiograms were performed prior to exercise testing. None of the patients was receiving digitalis preparations, propranolol, or antihypertensive agents. Nitroglycerin was withheld the day of exercise testing.

Each patient was exercised using the Bruce multistage
treadmill protocol. A single bipolar chest lead was employed with the positive electrode in the V_{5} position. Cuff blood pressure was monitored by a Propper Manufacturing Sphygmomanometer with ausculting diaphragm built into the cuff and positioned over the brachial artery. Blood pressure was recorded at rest, during the final minute of each three minute stage, at the first appearance of ST-segment depression, and every minute until the termination of the test, or at the onset of angina while the patient continued to exercise. All patients were exercised to the onset of their presenting symptom, which was either chest pain or dyspnea, but no patient exercised more than 60 seconds beyond the onset of his symptomatic angina. The fall in blood pressure was often abrupt and of considerable magnitude. Once this sign was recognized and confirmed by a second measurement made within fifteen seconds, the test was stopped.

Immediately following exercise, patients assumed a sitting position and blood pressure and ECG were monitored until they returned to normal resting levels. Blood pressure returned to normal within two minutes in all patients, and no complications resulted from the exercise testing.

Patients exhibiting hypotension with angina were advised to undergo coronary arteriography. Two patients died suddenly within six weeks of the exercise test prior to arteriography. One died at home shortly after the onset of spontaneous chest pain approximately six weeks after the treadmill test. No autopsy was performed. The second patient died suddenly while vacationing, also six weeks after the exercise test. This patient had refused arteriography. No autopsy was performed. The remaining patients were studied utilizing the percutaneous femoral approach described by Judkins. Each vessel was viewed in multiple projections using 35 mm cineangiography, and those arteries with greater than 75% narrowing were considered significantly narrowed. Six subjects underwent repeat exercise testing six weeks to two months following coronary bypass surgery. Characteristics of the group are shown in table 1.

### Results

**Exercise Testing**

Two patterns of abnormal blood pressure response were observed and these are depicted in figures 1 and 2. Three patients exhibited the pattern of a progressive fall in blood pressure from the first mo-

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Group Characteristics of 17 Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>55</td>
</tr>
<tr>
<td>Sex</td>
<td>Male 16</td>
</tr>
<tr>
<td></td>
<td>Female 1</td>
</tr>
<tr>
<td>Previous MI</td>
<td>7</td>
</tr>
<tr>
<td>Symptom of heart failure</td>
<td>0</td>
</tr>
<tr>
<td>Angina: Effort related</td>
<td>17</td>
</tr>
<tr>
<td>Resting</td>
<td>4</td>
</tr>
<tr>
<td>Dyspnea with angina</td>
<td>5</td>
</tr>
<tr>
<td>Dizziness with angina</td>
<td>2</td>
</tr>
<tr>
<td>Resting BP: Systolic</td>
<td>135 mm Hg 118-158</td>
</tr>
<tr>
<td></td>
<td>Diastolic</td>
</tr>
<tr>
<td>Cardiomegaly on X-ray</td>
<td>1</td>
</tr>
<tr>
<td>Physical findings:</td>
<td>8.3 gallop</td>
</tr>
<tr>
<td></td>
<td>Murmur</td>
</tr>
</tbody>
</table>

Systolic and diastolic blood pressure are plotted during treadmill exercise testing. In 1971 (dashed line) this patient exhibited a near normal exercise capacity without angina. In 1974 he developed angina at the end of stage 1 and systolic pressure abruptly fell, demonstrating a marked departure from the previous test. Exercise was stopped and blood pressure recovered.
on the treadmill was quite varied with some subjects unable to complete the first stage and others exercising into stage 3. One subject completed stage 3. Functional aerobic impairment was calculated from the normogram of Bruce, Kusumi and Hosmer and defines as a percentage the difference between observed exercise performance and that which would be predicted for a normal subject of the same age, sex and activity status. Only one patient exceeded a maximum heart rate of 150 and he is the only patient whose heart rate exceeded 85% of predicted maximum rate. The mean fall in systolic pressure was 29 mm Hg when compared with resting pressure, and 38 mm Hg compared with maximum pressure. Four patients developed their highest blood pressure during the recovery period, occurring as angina subsided (fig. 2); however, the recovery blood pressure was not used in calculating the magnitude of blood pressure change. ST-segment depression occurred in all patients but varied from mild to marked with eight patients exhibiting depression of 1–2 mm and four patients demonstrating 5 mm or more. Two patients developed spontaneous angina during supine cardiac catheterization. In each, a rise in systolic and left ventricular end-diastolic pressures resulted. In two patients in whom angina was induced by atrial pacing, systolic pressure did not fall as angina appeared.

Coronary Arteriography

As shown in table 3, five of fifteen patients had significant narrowing of the MLCA. In three it exceeded 90%. Fourteen of fifteen patients had severe proximal LAD and circumflex disease which, in terms of myocardial perfusion, may in some patients be equivalent to a MLCA lesion. The two patients without significant circumflex disease exhibited a dominant right coronary pattern with greater than 90% obstruction of the proximal RCA. Twelve showed significant narrowing of all three vessels. Resting left ventricular end-diastolic pressure (LVEDP) was 15 mm Hg or less in all patients. The angiographic ejection fraction was > 0.55 in six, 0.45–0.55 in seven and < 0.45 in two patients.

Table 2

<table>
<thead>
<tr>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Duration of exercise (sec)</td>
<td>140–540</td>
</tr>
<tr>
<td>2. Aerobic impairment (%)</td>
<td>0–65</td>
</tr>
<tr>
<td>3. Maximum HR (beats/min)</td>
<td>100–188</td>
</tr>
<tr>
<td>4. Nadir of systolic BP fall:</td>
<td></td>
</tr>
<tr>
<td>Compared with resting BP (mm Hg)</td>
<td>6–68</td>
</tr>
<tr>
<td>Compared with maximum BP (mm Hg)</td>
<td>10–68</td>
</tr>
<tr>
<td>5. ST-segment depression (mm)</td>
<td>1–7</td>
</tr>
</tbody>
</table>

Abbreviations: MCLA = main left coronary artery; LAD = left anterior descending coronary artery; LCC = left circumflex coronary artery; RCA = right coronary artery; LVEDP = left ventricular end-diastolic pressure; EF = ejection fraction.

Coronary Bypass Surgery

The results of repeat exercise testing following bypass surgery are illustrated in figure 3. In each patient, there was significant improvement in exercise capacity and loss of symptomatic angina and ST-segment depression. In each the hypotensive response was replaced by a normal or near normal rise of systolic pressure in response to exercise. Figure 1 graphically illustrates in the same individual the difference in blood pressure response before and after bypass surgery.

Discussion

This study demonstrates the importance of measuring blood pressure during treadmill exercise...
testing. Failure to recognize a fall in pressure exposes the patient to unnecessary risks from the testing process and deprives the clinician of information essential in his assessment of the disease process and his decision concerning therapeutic intervention. Each patient in this group exhibited a fall in systolic blood pressure during treadmill exercise-induced angina pectoris and all showed an unusually severe compromise of blood supply to the left ventricle with severe narrowing of the coronary vessels most responsible for left ventricular perfusion. We speculate that the fall in systolic pressure reflects acute, ischemia-induced left ventricular power failure, a sign not seen unless a large amount of left ventricular muscle is rendered ischemic by the testing process. Restoration of normal blood pressure response following bypass surgery which relieved angina and abolished ST-segment change suggests that ischemia was responsible for the hypotension.

Upright posture and rhythmic large muscle exercise appear to be essential in eliciting the sign since hypotension did not occur in supine patients when angina spontaneously appeared or was elicited by atrial pacing. We speculate that the obligatory vasodilatation of exercise permits impaired left ventricular function to become manifest by a fall in systolic pressure in contrast to the supine subject in whom vasoconstriction and augmented venous return may help maintain systolic pressure despite fall in contractility, stroke volume and cardiac output.⁹

We further speculate that in a patient with near normal resting ventricular function, a fall of systolic pressure during upright exercise does not become manifest unless a large amount of ventricular muscle is rendered ischemic. This conclusion is inferred from the extent of CAD required to produce this result.

Other mechanisms of exercise-induced hypotension should be considered and distinguished from the mechanism proposed above. Patients with obstructive valvular disease, particularly aortic and mitral stenosis, may exhibit hypotension during exercise because stroke volume and cardiac output may not increase appropriately. The usual fall in peripheral vascular resistance accompanying exercise results in the blood pressure fall.¹⁰ One patient in this series had mild mitral insufficiency and this accounts for the only valvular disease in this group.

Patients with severe chronic impairment of left ventricular function might similarly develop exertional hypotension.⁹ ¹⁰ In this series, no patients had clinical evidence of heart failure or significant elevation of LVEDP. Only two had more than mild reduction in angiographic ejection fraction and only one had cardiomegaly on chest X-ray. Acute mitral valve insufficiency induced by exercise and manifested by the appearance of a systolic murmur did not appear in any patient although such an event might influence the cardiac output and blood pressure response. Neurogenic influence, such as a vasovagal discharge, can produce profound postexercise hypotension. This is almost always associated with bradycardia and seldom occurs during submaximal exercise. None of this group developed bradycardia and all developed hypotension during submaximal exercise. Thus, vasovagal discharge seems an unlikely cause of the hypotension. Impaired autonomic function occurring as an effect of antihypertensive or propranolol therapy or occurring as a primary pathophysiologic disturbance does produce exercise and postexercise hypotension, but none of the patients were exposed to these drugs and none demonstrated orthostatic hypotension.¹¹ Hypotension commonly does occur during maximal exhaustive exercise in normal subjects.¹² ¹³ This should not be interpreted as an abnormal event as it occurs in most subjects who enter an anaerobic phase of the exercise effort. In this series of patients only one exceeded 85% of predicted heart rate and in most the exercise period was short and not exhaustive.

There has been criticism of the reliability and accuracy of external blood pressure measurements during exercise. It is our experience that reproducible blood pressures can be measured in most patients at lower levels of exercise including stages 1, 2 and 3. Beyond stage 3 arm and muscle motion interferes and reproducibility of the measurements diminishes. No patient in this series exceeded the stage 3 level of treadmill exercise.

Thus, we can qualify conditions under which exercise-induced hypotension may be interpreted as a sign of critical coronary artery narrowing. 1) There must be evidence of ischemia with ST-segment depression and/or symptomatic angina. 2) Signs of obstructive valvular disease and chronic moderate to severe left ventricular dysfunction should be absent. 3) Subjects must be free of the effects of antihypertensive and propranolol therapy and should not exhibit resting orthostatic hypotension. 4) Relative hypotension must be elicited at mild to moderate levels of exercise well within the predicted exercise capacity of each individual at a submaximal heart rate. 5) Bradycardia should not be a prominent feature of the response for this raises the possibility of a vasovagal response. 6) Reliable and reproducible blood pressures have been obtained.

If these qualifications are carefully observed then a significant fall in systolic pressure accompanying the onset of ST-segment depression and symptomatic angina is an easily elicited, reliable sign of critical coronary artery narrowing. It is a sign elicited by non-
invasive means and it may be specific for severe compromise of left ventricular blood supply. It thus has the potential of assisting in the identification of patients who are at greatest risk from coronary heart disease.

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References

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