Reversal of Exercise-induced Hemodynamic and Electrocardiographic Abnormalities after Coronary Artery Bypass Surgery

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SUMMARY Forty patients (35 men and five women) who experienced hypotension during maximal symptom-limited exercise test were retested after a 12 ± 4-month interval. Mean age was 53.5 years. All patients had multiple-vessel disease. Seventeen patients underwent coronary artery bypass surgery because of disabling angina, and 23 patients without disabling angina continued under medical management. At entry, there were no significant differences in age, left ventricular function or exercise performance between the medical and surgical groups.

At follow-up, the surgical group showed an average increase in the exercise duration of 2.2 ± 1.7 minutes (p < 0.001), maximal heart rate of 17 ± 15 beats/min (p < 0.001), maximal systolic blood pressure of 26 ± 23 mm Hg (p < 0.001) and maximal rate-pressure product of 60 ± 41 (p < 0.001). These measurements did not change significantly in the medically managed group.

Exercise-induced hypotension is apparently caused by ischemic left ventricular dysfunction, since in the majority of patients, it is reversible after successful revascularization. This observation is supported by the lack of improvement in a comparable group of patients managed without surgery.

EXERCISE-INDUCED blood pressure abnormalities are associated with severe coronary artery disease. 1-3 Although the mechanism of exartial hypotension is not known, it has been postulated to be secondary to ischemic left ventricular dysfunction. Several studies have demonstrated reversal of the hypotensive response after coronary revascularization, 1, 2, 4, 5 but it is not clear whether a medical program can achieve similar long-term results.

In this retrospective study, we assessed the long-term effects of medical management or coronary revascularization on serial exercise testing in patients with exertional hypotension.

Patients and Methods

Forty patients (35 men and five women) who experienced an abnormal blood pressure response during maximal symptom-limited treadmill exercise test and had repeat testing at 12 ± 4 months were studied. The average age was 53 years (range 36–73 years). An abnormal blood pressure response to exercise was defined as either a failure of the systolic blood pressure to increase at least 10 mm Hg after the first minute of exercise (five patients) or an initial rise in systolic blood pressure but subsequent fall of more than 20 mm Hg during continued exercise (35 patients).

Each patient was exercised using the Bruce multi-stage treadmill protocol. 6 Before the test, blood pressure and heart rate were taken with the patient supine, sitting and upright. Blood pressure and heart rate were then recorded at 1-minute intervals during exercise, immediately after exercise and every minute thereafter for 5–10 minutes. The ECG was continuously monitored and a recording was obtained at the end of each minute using bipolar leads X, Y, modified Lewis and Xa. Patients exercised to a symptom-limited end point, such as severe angina pectoris, fatigue or shortness of breath. Medications were not stopped before exercise testing. At the time of the initial test six patients were taking antihypertensive medications and three were taking propranolol. At repeat testing, four
TABLE 1. Exercise Data at Initial and Repeat Treadmill Test

<table>
<thead>
<tr>
<th></th>
<th>Medical</th>
<th>Coronary artery bypass</th>
<th>p*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise duration (min)</td>
<td>Initial</td>
<td>6.1 ± 1.9</td>
<td>5.5 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>6.0 ± 2.2</td>
<td>7.7 ± 2.2</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>-0.1 ± 2.0</td>
<td>2.2 ± 1.7</td>
</tr>
<tr>
<td></td>
<td>p†</td>
<td>NS</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Maximum heart rate (beats/min)</td>
<td>Initial</td>
<td>140.2 ± 12.9</td>
<td>134.2 ± 20.5</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>137.7 ± 19.0</td>
<td>150.8 ± 14.5</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>2.5 ± 15.1</td>
<td>16.6 ± 15.0</td>
</tr>
<tr>
<td></td>
<td>p†</td>
<td>NS</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Maximum systolic (mm Hg)</td>
<td>blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial</td>
<td>160.8 ± 26.7</td>
<td>156.0 ± 20.3</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>162.3 ± 30.7</td>
<td>181.7 ± 22.1</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>1.5 ± 20.6</td>
<td>25.7 ± 22.5</td>
</tr>
<tr>
<td></td>
<td>p†</td>
<td>NS</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Rate-pressure product</td>
<td>Initial</td>
<td>226.0 ± 45.0210.8 ± 33.7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>224.5 ± 55.3</td>
<td>270.4 ± 33.7</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
<td>-1.5 ± 42.3</td>
<td>59.6 ± 41.2</td>
</tr>
<tr>
<td></td>
<td>p†</td>
<td>NS</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>Drop in systolic</td>
<td>blood pressure</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Initial</td>
<td>33.8 ± 13.9</td>
<td>33.3 ± 14.7</td>
</tr>
<tr>
<td></td>
<td>Repeat</td>
<td>18.3 ± 15.7</td>
<td>7.7 ± 12.8</td>
</tr>
</tbody>
</table>

Values are mean ± SD.
*The p values between medical and coronary artery bypass represent differences between group means.
†The p values between initial and repeat tests were obtained by paired t-test analysis.

were taking antihypertensive medications and two were taking propranolol.

All patients underwent cardiac catheterization within 2 weeks of the initial treadmill test. Right- and left-heart catheterization was performed by the percutaneous femoral approach. Left ventricular cineangiograms and selective coronary arteriograms were recorded on 35-mm film at 60 frames/sec using a cesium iodide image-intensifier system. Coronary arterial stenosis was estimated as a percentage of luminal narrowing; stenosis greater than 70% was considered hemodynamically significant. Left ventricular volumes and ejection fraction were calculated from the right anterior oblique ventriculogram using the area-length method.7

At the initial evaluation, 17 patients were referred to elective coronary artery bypass surgery: 14 patients because of chronic disabling angina, one patient because of ventricular fibrillation during exercise, and two because of left main coronary artery disease. Twenty-three patients were recommended for medical management: 11 had mild stable angina, three had had a myocardial infarction 6 weeks previously and nine were asymptomatic. Of the stable angina patients, two had left main coronary artery disease and refused surgery.

All patients were encouraged to participate in an outpatient rehabilitation program of regular physical conditioning and modification of risk factors such as cigarette smoking, hypertension and obesity. Active patients exercised at least three times a week, for 30-45 minutes each time, at heart rates of 110 beats/min. The inactive patients failed to meet these criteria. Exercise testing and cardiac catheterization were repeated 12 ± 4 months after the initial study. Statistical significance between the exercise measurements and hemodynamic data, between the medical and surgical groups at initial and repeat studies, was determined by paired t test and chi-square analysis when appropriate.

Results

Treadmill Testing

Exercise duration, maximal heart rate, blood pressure and rate-pressure product at initial and repeat treadmill testing for both groups are shown in table 1. At entry, there was no significant difference in any of the exercise measurements between the medical and surgical groups. At follow-up, exercise duration decreased from 6.1 to 6 minutes (NS) in the medical group, but increased from 5.5 to 7.7 minutes (p < 0.005) in the surgical patients (fig. 1). This increase was highly significant (p < 0.0001).

The maximal heart rate decreased in the medical group from 140 to 138 beats/min (NS), but increased in the surgical group, from 134 to 151 beats/min (p < 0.01) (fig. 2). In the surgical group, the average increase was 17 beats/min (p < 0.0005). The maximal

![Figure 1](http://circ.ahajournals.org/Download/369.png)

**Figure 1.** Treadmill exercise duration (in minutes) at initial and repeat testing (12 ± 4 months). Seventeen patients underwent coronary artery bypass surgery (CAB) after initial testing; 23 patients were medically managed. Each line represents one patient. The mean ± SEM is indicated for each group. The p values were obtained by comparison of group means.
systolic blood pressure did not change in the medical group, while it increased in the surgical patients, from 156 to 182 mm Hg (p < 0.001) (fig. 3). In the medical group, maximal rate-pressure product decreased from 226 to 224 (NS); in the surgical group it increased from 211 to 270 (p < 0.0002) (fig. 4).

At initial testing, all patients had an abnormal blood pressure response at an average heart rate of 136 ± 15 beats/min and at a rate-pressure product of 218 ± 39. The average duration on the treadmill at the time of the drop in blood pressure was 5.4 ± 2.0 minutes. At repeat testing, only five of the surgical patients had a drop in systolic blood pressure; this fall occurred at significantly higher heart rate (155 ± 11 beats/min, p < 0.01), maximal rate-pressure product (268 ± 14.6, p < 0.01) and longer duration (8.7 ± 2.2 minutes, p < 0.002). In contrast, 18 of the 23 medical patients continued to have exertional hypotension at similar heart rates (130 ± 19 beats/min, NS), maximal rate-pressure product (209 ± 51 mm Hg, NS) and exercise duration (5.4 ± 1.9, NS) (table 2).

Changes in ST Segment and Angina During Exercise

At initial testing, 18 medical and 16 surgical patients had ≥ 0.1 mV flat or downsloping ST depression; 22 patients had ≥ 0.3 mV ST depression (fig. 5). Of the 23 medical patients, five (22%) improved their degree of ST-segment depression and 18 did not change or became worse. In contrast, 12 of the 17 surgical patients (71%) showed improvement in the degree of ST-segment depression. The difference between the two groups is highly significant (χ² = 11.9, p < 0.001).

In the surgical group, nine of 11 patients with angina on the initial test were free from angina at repeat study; eight of the 10 medical patients continued to have angina (χ² = 8.0, p < 0.005).

Hemodynamic Data

At initial cardiac catheterization there were no significant differences between the medical and surgical groups in resting hemodynamic variables (table

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**Figure 2.** Maximal heart rate (beats/min) on treadmill at initial and repeat testing (12 ± 4 months). Seventeen patients underwent coronary artery bypass surgery (CAB) after initial testing; 23 patients were medically managed. Each line represents one patient. The mean ± SEM is indicated for each group. The p values were obtained by comparison of group means.

**Figure 3.** Maximal systolic blood pressure (mm Hg) on treadmill at initial and repeat testing (12 ± 4 months). Seventeen patients underwent coronary artery bypass surgery (CAB) after initial testing; 23 patients were medically managed. Each line represents one patient. The mean ± SEM is indicated for each group. The p values were obtained by comparison of group means.

**Figure 4.** Maximal rate-pressure product on treadmill at initial and repeat testing (12 ± 4 months). Seventeen patients underwent coronary artery bypass surgery (CAB) after initial testing; 23 patients were medically managed. Each line represents one patient. The mean ± SEM is indicated for each group. The p values were obtained by comparison of group means.
In the 10 surgical patients with 27 vein grafts, 24 were patent and functioning well (89% patency rate); all patients had at least one graft patent. Four patients showed significant progression in the grafted coronary circulation; in all cases the progression was proximal to the insertion of the vein graft. Of the non-grafted vessels, there was significant progression in only one instance mentioned earlier in the text.

**Effect of Medications on the Blood Pressure Responses**

At the initial testing, three patients were taking propranolol (one from the medical group and two from the surgical group) and six were taking antihypertensive medication (two from the medical group and four from the surgical group). At repeat testing, two patients were taking propranolol (both in the medical group) and four were taking antihypertensive medication (two had been taking this medication at the initial test, and two were from the surgical group). To evaluate the effect of propranolol or antihypertensive medications on the blood pressure responses, 63 exercise tests were analyzed (46 from the 23 medical patients; and 17 from the surgical group, before coronary bypass surgery). Fifty tests were performed while patients were not taking these medications and 13 while they were. The average drop in systolic blood pressure from the 50 tests on no medication was 27 ± 17 mm Hg; and for the 13 tests while taking medication, 25 ± 16 mm Hg, (t = 0.30, NS). Further analysis was carried out on the 11 patients who were on medication at one test but not at the other. The average drop in systolic blood pressure was 18 ± 17 mm Hg while taking medication and 23 ± 20 mm Hg while not taking medication (t = 0.68, NS).

**Effect of Physical Conditioning on Exercise**

Fourteen patients were active (eight medical and six surgical) and 26 were inactive (15 medical and 11 surgical) (table 4).

At initial testing, there was a significant difference in exercise duration between the active and inactive patients in both groups. At repeat testing, further improvement in duration was noted only in the surgical

![Figure 5. Degree of ST-segment depression at initial and repeat testing (12 ± 4 months) in 17 patients who had coronary artery bypass surgery after the initial test and in 23 patients managed medically. The numbers within the circles represents the number of patients with the degree of ST-segment depression shown outside the circle. Each line represents one patient.]
The group (both active and inactive). In the medical group, exercise duration, maximal heart rate, maximal systolic blood pressure and double product did not change significantly at repeat testing; this response was noted in both active and inactive groups. In the surgical patients there was a trend toward improvement in all exercise measurements, which only achieved statistical significance in the inactive patients. The prevalence of blood pressure abnormalities at repeat testing was similar in the active and inactive groups and, because of the small number in each group, no statistical comparison was made.

**Discussion**

The association between exertional hypotension and severe coronary artery disease is well established.1-3 The present study shows that exercise-induced blood pressure abnormalities usually return to normal after successful coronary revascularization, and in the few patients who continued to show these abnormalities, they occurred at a significantly higher heart rate and at a longer duration on the treadmill. These data confirm the observations of Thomson and Kelleman,1 Morris et al.,2 and Li et al.3 and support the possibility of the role of exercise-induced ischemic left ventricular dysfunction as the most likely mechanism for the decrease in systolic blood pressure. This possibility is also supported by the fact that of a comparable group of 23 nonsurgical patients, 78% continued to have exercise-induced blood pressure abnormalities at similar heart rates and duration on the treadmill and 88% continued to have an ischemic ST-segment response during serial exercise testing over a 1-year period.

In addition to the improvement in exercise capacity and blood pressure response, the majority of surgical patients in our study also showed a significant decrease in ST-segment depression; normalization of the ischemic ST-segment responses after successful myocardial revascularization has been reported.4,5

The significant improvement in the exercise capacity in the surgical group was not reflected in the resting hemodynamic data obtained from the few patients who had repeat cardiac catheterization. The lack of improvement in resting ejection fraction in this study is consistent with previous reports.6-10 While resting ejection fraction does not change after coronary artery bypass surgery, exercise ejection fraction appears to improve significantly in the majority of patients.10 We believe that this mechanism is responsible for the significant improvement in exercise performance and blood pressure response in our patients.

The effect of antihypertensive medications on exercise-induced blood pressure abnormalities was examined in a previous report.1 We found no increased prevalence of these abnormalities in the 77 patients who were taking such medications compared with a group of 301 patients who were not. In our current study, 11 patients were taking medications at either initial or repeat study, but not both; the antihypertensive medications or propranolol did not play a significant role in the results.

Detry and Bruce showed significant increases in maximal heart rate and maximal rate-pressure product in 14 patients after training.11 In our study, even the active medical patients did not improve the
exercise measurements. The surgical patients, whether active or inactive, showed significant increases in the duration of exercise at repeat testing; maximal heart rate, maximal systolic blood pressure and the maximal rate-pressure product were significantly higher only in the inactive patients, although there was no significant difference in these measurements between the active and inactive surgical patients at repeat testing.

This limited experience with a rather small number of patients indicates that prolonging medical management is not beneficial in the majority of patients with angina and exercise-induced blood pressure abnormalities and who are otherwise suitable candidates for coronary artery surgery. This is further supported by the long-term follow-up study by Bruce and coworkers, who reported that in patients with coronary artery disease and exercise-induced left ventricular dysfunction, coronary artery bypass surgery significantly improved the 4-year survival, compared to a similar group managed medically.18 In our study, 10 of the 23 patients on medical management required coronary artery bypass surgery within 3 years after the initial study.

In conclusion, our study shows that successful coronary artery surgery normalized exercise-induced blood pressure abnormalities and improved exercise performance in the majority of patients with three-vessel disease, while medical management failed to show such improvement in a comparable group of patients.

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References

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