Cardiovascular Function during Early Recovery from Acute Myocardial Infarction

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SUMMARY Fifty patients with acute myocardial infarction were studied serially to evaluate the extent and nature of functional cardiovascular impairment and the time course of recovery. Reinfarction or death occurred in six patients. Peak workload during bicycle exercise in a subgroup of 25 patients with maximal initial test and complete follow-up increased from 334 to 409 kpm/min (P < 0.01) between three and six weeks. There was further significant (P < 0.01) improvement between three and six months from 438 to 488 kpm/min. The incidence of ischemia at a constant workload decreased between three and six weeks without any significant changes in heart rate or blood pressure. Mean cardiac output during exercise at three months was 6.5 and at six months 7.8 L/min (P < 0.05). Corresponding values for stroke volume were 61 and 72 ml (P < 0.05).

The data suggest that in clinically stable patients there is an early improvement of the relation between myocardial oxygen supply and demand and a late improvement of functional capacity associated with increased stroke volume and cardiac output.

CARDIOVASCULAR FUNCTION has been studied extensively during the acute and late chronic stages of myocardial infarction. In particular, determinants of optimal left ventricular performance and the interrelationships between infarct size, hemodynamic findings and in-hospital mortality and morbidity have been well established. Hemodynamic conditions at rest and during exercise have been characterized in patients with remote myocardial infarction, and a large amount of data is available on exercise performance during the late chronic stage. Exercise studies have recently also been performed at the time of hospital discharge but little is known about cardiovascular function during the period between discharge and several months later. The purpose of the present study was to define the extent and nature of functional impairment and the time course of recovery during the initial six months following an acute myocardial infarction.

Material and Methods

The series included 50 patients, 43 men and 7 women, with mean age of 52.8 years and a range of 29 to 67 years. Fourteen patients had anterior, 22 inferior, and 14 subendocardial infarction. The diagnosis of infarction was based on the presence of each of the following findings: 1) history of prolonged pain with distribution consistent with myocardial infarction (subternal, arm, neck, or jaw); 2) enzyme abnormalities, i.e., elevated serum levels of creatine phosphokinase and glutamic oxaloacetic transaminase; 3) positive technetium-99m stannous pyrophosphate myocardial scintigram; 4) characteristic ECG abnormalities, including evolutionary QRS and ST-T changes in transmural myocardial infarction and evolutionary ST-T abnormalities in subendocardial infarction.

Thirteen patients (26%) had a history of previous myocardial infarction. Reasons for exclusion were limited to age above 67 or condition precluding ambulation and exercise testing, e.g., severe left ventricular failure, angina pectoris at rest, or cerebral vascular disease. Ninety-two percent of the eligible patients participated in at least one follow-up study after discharge and 56% completed the series of four studies. The most common medical reason for exclusion from further study were recurrent infarction and coronary artery surgery, each occurring in four patients. There were three deaths. Details are provided in table 1.

Medications included digoxin in nine patients, propranolol in six, and nitrates in twenty-nine. Dosages were kept constant through the study period. Twenty-two patients were treated with oral antiarrhythmic agents. There was no formal rehabilitation program but the patients were encouraged to increase gradually their level of physical activity.

Studies were performed one day prior to hospital discharge, usually three weeks after the onset of myocardial infarction, with follow-up at six weeks, three months, and six months. Isometric exercise testing, i.e., sustained handgrip, was performed as the initial procedure following physical examination and ECG at rest. Methods have been described elsewhere. Dynamic exercise testing was performed in the upright position on a mechanical bicycle ergometer at progressively heavier workloads with a duration of three minutes at each load. Workloads were measured in kilopond meters/min (kpm/min). The test at discharge was terminated in asymptomatic patients at a heart rate of 130 beats/min. The target of subsequent tests was a symptom-limited maximal level. Exercise was discontinued at intensities below the target level if any of the following symptoms or signs developed: 1) chest, jaw, neck or arm pain that was progressive and suggestive of myocardial ischemia; 2) ST-segment displacement (horizontal) of at least 1 mm from the level at rest; 3) multifocal or frequent ventricular premature beats (more than 1/5 conducted beats) or sustained supraventricular arrhythmias; 4) cyanosis, weakness, dizziness, or inadequate blood pressure response, suggestive of depressed left ventricular function. The ECG was monitored and recorded continuously utilizing a modified Frank lead system. Oxygen uptake was estimated from workload and
duration of exercise according to the method by Strandell as modified by Sanne. 

Cardiac output was determined by our modification of the acetylene rebreathing technique, employing a mass spectrometer (Medspec I) for measurement of gas concentrations. An on-line Digital Equipment PDP 12 computer was used for calculation of the disappearance rate of acetylene which is proportional to pulmonary blood flow. The method has recently been described in detail. Comparison with simultaneously obtained cardiac output measurements by the indicator dilution method has established a standard error of estimate of 4.5% and a linear correlation coefficient of 0.94 over the range of 5–19 L/min. Cardiac output was determined during a separate procedure with the patient sitting at rest on the bicycle ergometer and during exercise after three minutes at 60% of the peak load achieved at the standard exercise test as described. The interval between the two exercise periods was at least one-half hour, and no measurements were made until monitoring of heart rate, blood pressure, and electrocardiogram had demonstrated return to the control state.

Standard statistical procedures were used, i.e. paired and group t-test and the chi-square test.

Results

Figure 1 shows serial mean data on peak workload during a symptom-limited exercise test. This measurement may be taken as an index of the functional capacity of the cardiovascular system. The total series shows a significant (P < 0.01) increase from 333 to 439 kpm/min between three and six weeks, but no significant subsequent changes. The

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**TABLE 1. Number of Follow-up Studies and Reasons for Nonparticipation**

<table>
<thead>
<tr>
<th></th>
<th>3 weeks</th>
<th>6 weeks</th>
<th>3 months</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of patients</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>remaining in study</td>
<td>50</td>
<td>46</td>
<td>38</td>
<td>28</td>
</tr>
<tr>
<td>(Percent)</td>
<td>(100)</td>
<td>(96)</td>
<td>(76)</td>
<td>(56)</td>
</tr>
<tr>
<td>Cumulative losses due to</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Death</td>
<td>—</td>
<td>—</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reinfarction</td>
<td>—</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Coronary surgery</td>
<td>—</td>
<td>—</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Other C.V. disease</td>
<td>—</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Refusal</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>Lost to follow-up</td>
<td>—</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>50</td>
<td>50</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

**FIGURE 1. Peak workload (kpm/min) during bicycle exercise.** Mean values ± standard error of the mean for the total series (left panel), a subgroup consisting of the 25 patients who achieved a symptom-limited maximal load at the initial test on discharge at three weeks (middle panel), and the smaller group of 13 patients who achieved a maximal load at the initial test and were available for study on each of the subsequent examinations. The increases in workload between three and six weeks, expressed as percent of the peak load at the initial test, were significant in all groups (P < 0.01, P < 0.01, and P < 0.02, respectively).

**FIGURE 2. Estimated oxygen uptake during symptom-limited maximal bicycle exercise as percent of age and sex-specific normal mean values.** The test was discontinued at a predetermined heart rate of 130 in asymptomatic patients at the initial test at hospital discharge (three weeks).

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mean value at discharge represents an underestimate since 25 asymptomatic patients were stopped at the predetermined submaximal heart rate of 130 bpm but the time course of recovery of function was similar in the subgroup of 25 patients who had a symptom-limited maximal test at the initial study and in the 13 of these patients who had maximal tests at each follow-up study (fig. 1). The mean peak workload ± standard error (in kpm/min) of the 25 patients with initial maximal tests was 334 ± 22 at three weeks, 409 ± 32 at six weeks, 438 ± 38 at three months and 488 ± 49 at six months, while the corresponding values for 13 patients who completed four maximal tests were 328 ± 30, 412 ± 48, 425 ± 36, and 488 ± 50. The difference between the values at three and six weeks, expressed as percent of peak load at initial test, was statistically significant in both groups (P < 0.01 and P < 0.02), but there were no significant differences between observations at subsequent time intervals.

Individual data on estimated peak oxygen uptake are displayed in figure 2. Oxygen uptake, calculated from workload and duration of exercise, is expressed as percent of age and sex-specific expected average normal values, corrected for body size. Mean values were 46% of expected at discharge, 56% at three weeks and three months, and 59% at six months. There was a wide interindividual variation from 25% to nearly 100% of expected.

There was no significant relationship between estimated peak oxygen uptake and infarct type and localization. Symptoms and signs during maximal exercise levels are shown in table 2.

The response to symptom-limited maximal exercise, including changes occurring during the period of follow-up, was analyzed in detail in a subgroup of 28 patients who completed three maximal tests at six weeks, three months, and six months (table 3). Peak workload increased significantly (P < 0.01) between six weeks and six months from 437 ± 30 to 514 ± 37 kpm/min. There were no significant changes with respect to peak heart rate, systolic blood pressure, or rate-pressure product. The number of patients with suggestive evidence of myocardial ischemia, defined as angina, ST displacement more than 1 mm from levels at rest, or frequent or complex ventricular premature beats, did not change significantly in this subset with complete studies. However, it should be noted that progression of the clinical manifestations of ischemia occurred in several patients in the total study population (table 1).

The response to exercise at a constant workload of 300 kpm/min is described in table 4. The analysis was based on a subgroup of 25 patients who were available for study at each of the four follow-up examinations. There was a progressive and significant decrease in heart rate during exercise but no change in systolic blood pressure. Nine patients had suggestive evidence of myocardial ischemia at three weeks but ischemia was precipitated in only three at six weeks. There was no change in the rate-pressure product. All four patients with angina at three weeks were angina free at the same workload at six weeks. The incidence of angina pectoris was also lower at six weeks in the total series. Nine of 50 patients had angina at three weeks and three of 46 at six weeks.

Serial mean cardiac output data at rest and during exercise are shown in table 5. There were no changes during the first three months but a significant increase between three and six months both at rest and during exercise. Estimated oxygen uptake during exercise was only 12% higher at six months but cardiac output increased by 20%.

Stroke volume at rest and during exercise (table 6) followed a similar pattern. The changes in cardiac output and stroke volume remained significant also when only the 20 patients who were studied at both three and six months were included in the comparison (P < 0.01).

Table 2. Symptoms and Signs during Maximal Exercise

<table>
<thead>
<tr>
<th>Time</th>
<th>No. of patients</th>
<th>Fatigue or shortness of breath</th>
<th>Angina pectoris</th>
<th>ST changes without angina or ST changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 weeks</td>
<td>46</td>
<td>20</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>3 months</td>
<td>38</td>
<td>12</td>
<td>7</td>
<td>17</td>
</tr>
<tr>
<td>6 months</td>
<td>28</td>
<td>15</td>
<td>4</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 3. Response to Symptom-limited Maximal Exercise in 25 Patients

<table>
<thead>
<tr>
<th>Time</th>
<th>Workload (kpm/min)</th>
<th>Heart rate (beats/min)</th>
<th>Systolic blood pressure (mm Hg)</th>
<th>RPP</th>
<th>Evidence of ischemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 weeks</td>
<td>445 ± 30</td>
<td>131 ± 4</td>
<td>147 ± 6</td>
<td>4</td>
<td>14 (50%)</td>
</tr>
<tr>
<td>3 months</td>
<td>454 ± 27</td>
<td>124 ± 4</td>
<td>153 ± 5</td>
<td>5</td>
<td>15 (50%)</td>
</tr>
<tr>
<td>6 months</td>
<td>528 ± 35*</td>
<td>125 ± 4</td>
<td>155 ± 6</td>
<td>12</td>
<td>12 (43%)</td>
</tr>
</tbody>
</table>

Table 4. Response to Exercise at a Constant Workload of 300 kpm/min in 25 Patients

<table>
<thead>
<tr>
<th>Time</th>
<th>Heart rate (beats/min)</th>
<th>Systolic blood pressure (mm Hg)</th>
<th>RPP</th>
<th>Evidence of ischemia</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 weeks</td>
<td>115 ± 3</td>
<td>137 ± 6</td>
<td>160 ± 8</td>
<td>9 (36%)</td>
</tr>
<tr>
<td>6 weeks</td>
<td>113 ± 3</td>
<td>138 ± 6</td>
<td>160 ± 8</td>
<td>3 (12%)</td>
</tr>
<tr>
<td>3 months</td>
<td>107 ± 3*</td>
<td>139 ± 6</td>
<td>154 ± 8</td>
<td>4 (16%)</td>
</tr>
<tr>
<td>6 months</td>
<td>101 ± 3*</td>
<td>139 ± 5</td>
<td>145 ± 7</td>
<td>4 (16%)</td>
</tr>
</tbody>
</table>

*Heart rates at 3 and 6 months were significantly (P<0.01) lower than at 3 weeks.

**Mean maximal workload was significantly (P<0.01) higher at 6 months than at 3 months.

\[\text{RPP} = \text{Rate-pressure product} = \text{Heart rate (beats/min)} \times \text{Indirect Systolic Blood Pressure (mm Hg)} \times 10^{-4}.\]
TABLE 5. **Cardiac Output at Rest and during Exercise**

<table>
<thead>
<tr>
<th></th>
<th>3 weeks</th>
<th>6 weeks</th>
<th>3 months</th>
<th>6 months</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac output, rest (L/min)</td>
<td>3.6 ± 2</td>
<td>3.8 ± 2</td>
<td>3.8 ± 2</td>
<td>4.7 ± .3*</td>
</tr>
<tr>
<td>Cardiac output, exercise (L/min)</td>
<td>6.5 ± .4</td>
<td>6.4 ± .3</td>
<td>6.5 ± .4</td>
<td>7.8 ± .5*</td>
</tr>
<tr>
<td>Estimated O$_2$ uptake, exercise (L/min)</td>
<td>0.77 ± 0.03</td>
<td>0.9 ± 0.04</td>
<td>0.96 ± 0.04</td>
<td>1.07 ± 0.06</td>
</tr>
<tr>
<td>N</td>
<td>40</td>
<td>40</td>
<td>32</td>
<td>20</td>
</tr>
</tbody>
</table>

*Mean values for cardiac output at rest and during exercise were both significantly (P < 0.005 and P < 0.01) higher at 6 months than at 3 weeks.

Discussion

The results indicated that at discharge 50% of the patients were unable to reach a heart rate of 130 beats/min without limiting symptoms or signs. Subsequent exercise tests confirmed that most patients with recent myocardial infarction have significantly reduced functional capacity of the cardiovascular system, measured as peak workload and estimated oxygen uptake during a progressive exercise test. There were large interindividual variations. The degree of physical impairment ranged from none to severe. New information emerged on the time course of recovery of cardiovascular function. In the subgroup of patients available for serial studies there was an early phase of improvement, (three to six weeks) associated with more favorable myocardial oxygen supply/demand ratio as judged by clinical and electrocardiographic estimates of the threshold of myocardial ischemia, and a late phase (three to six months) with increased stroke volume and cardiac output at rest and during exercise.

The study group consisted of an unselected series of patients drawn from a large city hospital. Only patients in functional class IV and patients older than 67 years were excluded. Standard forms of treatment were employed. Drug selections and dosages were kept constant in each individual patient during the study period. There was no formal physical training program but each patient was encouraged to extend gradually his range of physical activity.

The overall data were probably affected by selective losses of patients during the study, particularly by the loss of patients with unfavorable course and prognosis. Such attrition is likely to occur in any population of patients after myocardial infarction. There were relatively few dropouts due to lack of cooperation or information on the patient's whereabouts. The data characterizing the series at various intervals after myocardial infarction should therefore be valid. However, it must be assumed that the unavoidable drop-outs introduced changes in group mean data also in the absence of any corresponding individual sequential changes. Findings in the total series were therefore confirmed by the analysis of subgroups of patients with complete data whenever possible.

**Physical Work Capacity and Time Course of Recovery**

We have been unable to document any previous studies in which unselected groups of patients with myocardial infarction have been followed over the entire initial six month period of recovery. Longitudinal studies during the late recovery phase have yielded equivocal results with respect to the degree of spontaneous improvement of function. Sanne$^4$ reported no significant changes in maximal workload between three and twelve months in a series of 110 patients who served as a control group in a study evaluating the effects of physical training. A subgroup of patients limited by angina pectoris improved by 17% but intragroup variation was large and the difference was not significant. Ken-

<table>
<thead>
<tr>
<th>Time of study</th>
<th>Heart rate (beats/min)</th>
<th>Systolic blood pressure (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>During exercise</strong></td>
<td><strong>Change from resting value</strong></td>
</tr>
<tr>
<td>3 weeks</td>
<td>89 ± 3</td>
<td>+13 ± 2</td>
</tr>
<tr>
<td>6 weeks</td>
<td>86 ± 2</td>
<td>+13 ± 2</td>
</tr>
<tr>
<td>3 months</td>
<td>84 ± 2</td>
<td>+11 ± 1</td>
</tr>
<tr>
<td>6 months</td>
<td>82 ± 2</td>
<td>+14 ± 2</td>
</tr>
</tbody>
</table>

*Mean stroke volumes at rest and during exercise were significantly higher at 6 months than at 3 weeks (P < 0.01, paired t-test).
talas described a significant decrease in heart rate at a given submaximal work load between two and five months postinfarction which suggests improved maximal performance.

Considerable information on exercise performance is available from cross-sectional studies. The results of several studies based on a low-level submaximal test at the time of hospital discharge are in general agreement with our data. About 50 to 60% of patients are, at the end of the third week after an acute myocardial infarction, able to tolerate an energy expenditure of three to four times resting levels and reach a heart rate of 120–130 beats/min without abnormal symptoms and signs. Ibns et al. performed a symptom limited maximal test during the third week after infarction in an unselected series of 209 patients. The median maximal work load was 400 kpm/min with a peak heart rate of 129. Fifty-eight percent of the patients were limited by fatigue only. These data are similar to our findings at six weeks.

Previous studies of patients with remote myocardial infarction have generally also demonstrated a significant reduction in physical work capacity. Mean values of peak oxygen uptake range from 50 to 80% of age and sex-specific normal reference data. The large variation between series is attributable to several factors, including test methodology and varying criteria for selection of patients. Sann's series is unique in providing data on a large, unselected patient population, studied at uniform intervals after infarction. Mean maximal oxygen uptake in 202 male patients three months after infarction was 21.3 ml/kg × min compared to 30.4 in an age-matched control group, i.e., 70% of expected. Fifty-five percent of the male patients in Sann's series had a physical performance capacity within normal limits. Corresponding data in our series at three months were less favorable with a mean of 56% of expected and only 13% of the patients achieving an estimated peak oxygen uptake within normal limits, defined as at least 75% of normal mean values.

Mechanisms Limiting Physical Performance

Myocardial Ischemia

The proportion of patients who were limited by symptoms and signs suggesting myocardial ischemia at peak exercise levels remained stable and approximated 50% (tables 2 and 3) throughout the study period. This figure includes patients with ventricular arrhythmias. Ventricular ectopy is generally regarded as a nonspecific abnormality but ischemia is the most likely mechanism in the patient group under study. The incidence of ventricular arrhythmias in the absence of ST abnormalities and angina was low.

The data presented in table 4 are consistent with the data on maximal performance and suggest that the relation between myocardial oxygen demand and supply improved during the period between three and six weeks after infarction. The number of patients with symptoms and signs of ischemia at a given level of exercise tended to decrease in the absence of any significant changes in heart rate or systolic blood pressure. The change in the number of patients with ECG manifestations of ischemia was associated with a similar decrease in the number of patients with angina pectoris. The lower incidence of exercise-induced ischemia at six weeks in the subgroup of patients with complete studies may reflect an improved myocardial oxygen supply or a decrease in myocardial oxygen demand that was not accounted for by the product of heart rate and systolic blood pressure. The rate-pressure product is closely correlated with myocardial oxygen uptake and coronary blood flow in normal subjects and provides a reproducible estimate of the threshold of ischemia in patients with angina pectoris. However, the product disregards two major determinants of myocardial oxygen demand, contractile state and ventricular volume. A decrease in myocardial oxygen demand due to a reduction in left ventricular volume and a decreased contractile state during exercise is an unlikely explanation of our findings since stroke volume and heart rate both remained unchanged. The data suggest an improved myocardial oxygen supply but confirmatory studies, including specific methods of measurement of coronary blood flow, left ventricular dimensions, and contractile state, are obviously needed.

The studies at three and six months demonstrated significantly lower heart rates at a reduced rate-pressure product at a given level of total body work. The changes were small but were in agreement with findings reported by others and are consistent with decreased myocardial work at any given level of total body energy expenditure.

Differences with respect to test methodology and criteria make it difficult to evaluate the role of exercise-induced myocardial ischemia as a mechanism limiting physical performance after myocardial infarction. More information is also needed on the interrelation between symptoms and signs of myocardial ischemia and segmental and total left ventricular performance. Most series, including our own, have demonstrated a markedly low incidence of angina pectoris.

Fatigue or dyspnea was the end point in 70% of the patients in the large series studied by Ibsen et al. at three weeks. Angina occurred in only 11%, but ST displacement of at least 1 mm was present in 63% of patients without bundle branch block or left ventricular hypertrophy. Ericson et al. reported angina in 20% and ventricular arrhythmias in 16% at a low level test at three weeks. Angina pectoris was the limiting factor in 34% of the patients in Sann's series and arrhythmia in 10% during a maximal test at three months.

The prognostic significance of the electrocardiographic manifestations of ischemia, including ventricular arrhythmias, during the early recovery phase is still uncertain. Available data are inadequate in terms of number of patients studied and the number of subsequent events. There is suggestive evidence that exercise-induced ischemia is associated with increased morbidity and mortality in patients with recent and remote myocardial infarction. Data from a small group of patients with anterior infarction studied serially over the period three weeks to 18 months by Atterhög et al. suggests that ST elevation during exercise represents a transient stage in many patients and it is possible that the prognostic implications of ST elevation during exercise are different during early and late recovery.

The workload required to precipitate ischemia is inversely related to the rate of future clinical events in patients with chronic coronary disease. To what extent this finding is applicable to patients with recent myocardial infarction also...
remains to be established, but a low threshold of ischemia in our series was associated with widespread and severe coronary arterial disease according to angiography.

Cardiac Output and Stroke Volume

Mean values of cardiac output and stroke volume at the initial study demonstrated a marked reduction compared to values for normal middle-aged men. Only patients with relatively high work capacity tended to have cardiac outputs and stroke volumes within the normal range. Both cardiac output and stroke volume remained unchanged during the initial three months but improved significantly between three and six months.

Several previous studies on cardiac output in patients with remote myocardial infarction have demonstrated reduced stroke volume and maximal cardiac output but a normal or near normal cardiac output at any given level of oxygen uptake with an appropriate increase in cardiac output for any given increase in oxygen uptake during submaximal work. The reduction in stroke volume is offset by compensatory increase in heart rate. Similar findings have also been reported from studies of patients with other forms of cardiac disease. The majority of the patients in our series, as well as in a group of patients with remote infarction and clinical evidence of left ventricular failure studied by Foster et al. did not show the expected compensatory increase in heart rate, and cardiac output remained abnormally low at submaximal levels of work.

Multiple mechanisms are involved in the regulation of stroke volume and cardiac output after infarction. A depressed functional state of the left ventricle due to ischemia and loss of muscle mass is most likely a major factor, but extracardiac mechanisms, particularly those affecting ventricular filling pressures, may also be important, especially immediately after hospital discharge, i.e., following a period of bed rest and restricted physical activity. Bed rest is associated with a decreased blood volume and probably also with regulatory changes affecting the capacitance vessels resulting in increased venous pooling in the upright position. However, data on cardiac output in normal subjects after prolonged bed rest demonstrate a pattern with a reduced cardiac output at rest but normal increments in heart rate with increasing oxygen uptake during exercise.

There is growing evidence that severe chronic heart disease is associated with dysfunction of the autonomic nervous system. The diminished blood pressure response to isometric exercise and the absence of compensatory tachycardia during dynamic exercise in our series may be attributed to the abnormal circulatory reflex regulation. The findings may reflect a generalized blunting of the autonomic response to stress, but it is also possible that the normal reflex mechanisms mediating the increased heart rate and/or peripheral resistance during isometric exercise and the increased heart rate during dynamic exercise are opposed by cardiovascular depressor activity due to activation of left ventricular mechanoreceptors or high pressure baroreceptors. There is experimental evidence indicating that ischemic segmental wall motion abnormalities produce bradycardia and peripheral vasodilation by this mechanism.

The combination of markedly reduced stroke volume and an attenuated heart rate response produces a severe reduction of maximal cardiac output, but our results indicate that stroke volume is likely to improve between three and six months postinfarction. Similar observations have also been made by Detry who reviewed several small series of patients serving as sedentary controls in studies on physical training.

Our study demonstrates wide individual variations with respect to the degree of cardiovascular function impairment following myocardial infarction. In clinically stable patients there was a small but significant improvement of exercise performance during the initial six months. Several mechanisms appear to be involved, including a possible increase in myocardial oxygen supply, decreased myocardial oxygen demand at any given level of total body work and increased stroke volume and cardiac output.

References

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Influence of Reduction of Preload and Afterload by Nitroglycerin on Left Ventricular Diastolic Pressure-Volume Relations and Relaxation in Man

PHILIP A. LUDBROOK, M.D., JOSEPH D. BYRNE, CPT, PETER B. KURNIK, M.S., AND ROBERT C. MCKNIGHT, M.D.

With the technical assistance of Frank R. Reed

SUMMARY To clarify the mechanisms of afterload reduction on left ventricular diastolic function, the influence of nitroglycerin upon ventricular diastolic pressure-volume relations was studied in 22 patients during catheterization. After nitroglycerin, average ventricular systolic pressure declined by 25 mm Hg (18%) and end-diastolic pressure by 7 mm Hg (28%) (P < 0.005). End-systolic and diastolic ventricular volumes decreased by 37% and 23% respectively (P < 0.005). Although peak negative dP/dt fell by 22% (P < 0.0005), "T," an index of the time course of isovolumic diastolic ventricular relaxation, was insignificantly changed.

SALUTORY EFFECTS of reduction of left ventricular afterload using vasodilator therapy in acute myocardial infarction and left ventricular decompensation are well recognized.1 Such benefits are thought to be associated with improvement in the ratio of myocardial oxygen supply to demand, resulting in part from reduced left ventricular afterload4 and in part from relatively enhanced coronary perfusion of the subendocardial regions critically prejudiced by reduction of left ventricular diastolic pressures.5

Although changes in the systolic function of the left ventricle in response to vasodilator therapy have been described,6 little information is presently available concerning simultaneous changes in diastolic properties of the ventricle. A traditional concept of left ventricular diastolic pressure-volume relations has assumed that the ventricle
Cardiovascular function during early recovery from acute myocardial infarction.
A J Wohl, H R Lewis, W Campbell, E Karlsson, J T Willerson, C B Mullins and C G Blomqvist

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