CLINICAL EVALUATION OF LEFT VENTRICULAR PERFORMANCE
IN PATIENTS WITH MYOCARDIAL INFARCTION

—Comparison of Hemodynamic Responses to Exercise and Angiographic Findings—

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In order to evaluate the left ventricular performance during exercise in patients with myocardial infarction, we performed a symptom-limited multistage exercise test using a bicycle ergometer in the supine position on 82 patients with myocardial infarction, and their hemodynamic responses to exercise were analyzed. Patients were subdivided into three groups according to the levels of pulmonary capillary wedge pressure (PCWP) and cardiac index (CI) obtained at the end-point of the exercise: Group I (20 patients) with PCWP < 18 mmHg and CI > 5.0 L/min/m²; Group II (32 patients) with PCWP ≥ 18 mmHg and CI > 5.0 L/min/m²; Group III (30 patients) with PCWP ≥ 18 mmHg and CI < 5.0 L/min/m².

Exercise tolerance expressed as the duration of exercise was 11.9 ± 0.5 (SEM) min in Group I, 10.6 ± 0.4 in Group II and 7.8 ± 0.5 in Group III, which was closely correlated with the left ventricular function observed at the end-point of the exercise. During exercise stroke volume index (SVI) decreased slightly in Group III, while it increased significantly in Groups I and II. The extent of coronary artery lesion in Group III was more severe than in Groups I and II. In 50 patients without prior myocardial infarction, infarct size estimated by total released CPK was larger in Group III than in Group I.

These findings indicate that coronary artery lesion and infarct size are important factors contributing to left ventricular performance during exercise in patients with myocardial infarction.

ONE of the most important problems in the management of patients with acute myocardial infarction is to establish a reliable guideline for physical activity in their daily life after discharge. Exercise test is a useful method for evaluating cardiac reserve in patients with myocardial infarction and has been widely used. The purpose of the previous studies using exercise stress test, however, has been mainly focused on detecting arrhythmias, evaluating ST segment changes or estimating the prognosis of the patients.1-5 Only few studies have been at-

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tempted to assess the left ventricular performance during exercise. In this study, therefore, we attempted to evaluate left ventricular hemodynamics at rest and during exercise in patients with myocardial infarction and elucidate the relationship between the hemodynamic response to exercise and infarct size or coronary artery lesion which may be considered factors contributing to left ventricular function during exercise.

MATERIALS AND METHODS

Patients
Eights-two patients, 74 men and 8 women with a mean age of 55.1, ranging from 29 to 70, were studied. All patients had transmural myocardial infarction documented by history, serial electrocardiograms and characteristic serum enzyme changes. Seventy-two patients had no previous history of myocardial infarction (anterior infarction: 45 patients; inferior infarction: 27 patients) and 10 patients had a history of previous myocardial infarction. Patients with valvular heart disease, chronic obstructive pulmonary disease or atrial fibrillation and patients receiving cardiac glycosides, nitrates or β-adrenergic blocking agents at the time of the exercise study were all excluded from this study. Patients in whom angina developed during exercise were also excluded. All patients were in class I or II according to the New York Heart Association classification and no patient had congestive heart failure. An exercise test using a bicycle ergometer and selective coronary arteriography were performed on all patients during their hospitalization about 2 months after the onset of infarction.

Bicycle Ergometer Exercise Test
The patients were examined in fasting state and all medications were stopped at least for 24 hours before the study. After 12-lead electrocardiogram was recorded at rest, symptom-limited multistage exercise test using a bicycle ergometer was performed in the supine position. Initial work load was set at 150 kpm/min and work load was increased by 150 kpm/min every 3 min. Exercise test was discontinued by the monitoring physicians if dyspnea and leg fatigue prevent further exercise, or marked elevation of blood pressure occurred. Precordial leads (V4-V6) were monitored continuously throughout the exercise test and a standard 12-lead electrocardiogram was recorded at the end-point of the exercise.

For all patients we determined the duration of exercise in minutes as an expression of exercise tolerance and calculated the product of heart rate and systolic blood pressure (rate pressure product: RPP) both at rest and at the end-point of the exercise.

Hemodynamic Studies
A flow-directed balloon catheter was inserted percutaneously via antecubital vein or femoral vein for determination of pulmonary arterial pressure and pulmonary capillary wedge pressure (PCWP). Arterial blood pressure was measured using an arterial cannula inserted percutaneously into the radial artery. Cardiac output was determined by the indicator dilution method using indocyanine green. Heart rate measured from the electrocardiogram was determined simultaneously with cardiac output measurements. Blood oxygen saturation levels were determined from blood gas analysis (ABL 2 Acid-Base Laboratory, Radiometer/Copenhagen). Stroke volume index, arterial-mixed venous oxygen difference and oxygen consumption were calculated from the measured variables as follows: 1) SVI = CO/HR/BSA, where SVI is stroke volume index in ml/beat/m², CO is cardiac output in L/min, HR is heart rate in beats/min and BSA is body surface area in m², 2) a-vDO₂ = (aSAT - vSAT) × Hb × 1.34, where a-vDO₂ is the arterial-mixed venous oxygen saturation difference, aSAT is the radial arterial oxygen saturation, vSAT is mixed venous oxygen saturation obtained from the pulmonary arterial blood, Hb is hemoglobin concentration in g/dl, and 1.34 is the factor which indicates the oxygen capacity of 1 g of hemoglobin. Hemodynamic measurements were also performed at rest and at the end-point of the exercise.

Cardiac Catheterization
Right and left heart catheterization and selective coronary arteriography were performed using the Judkins technique. Coronary angiography was performed on 35 mm film at multiple views. Each coronary arteriogram was interpreted by two observers without any knowledge of the clinical status and hemodynamic response to the exercise. A stenosis of 75% or more of coronary artery was defined as a significant narrowing. Infarct size was obtained as the total CPK released (ΣCPK) from serial determinations of CPK activities by Sobel's method in 50 patients without prior myocardial infarction.

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exercise in all patients. For further study, patients were subdivided into three groups according to the levels of PCWP and CI at the end-point of the exercise:

- **Group I (20 patients):**
  - PCWP < 18 mmHg, CI ≥ 5.0 L/min/m²,
- **Group II (32 patients):**
  - PCWP ≥ 18 mmHg, CI ≥ 5.0 L/min/m²,
- **Group III (30 patients):**
  - PCWP ≥ 18 mmHg, CI < 5.0 L/min/m².

**Resting Hemodynamics**

Hemodynamic data at rest and at the end-point of the exercise for individual patients are summarized in Tables I and II. Among three groups no significant differences in heart rate, mean arterial pressure, rate pressure product and arterio-mixed venous oxygen difference at rest were found. Cardiac index and stroke volume index in Group III were smaller than those in Groups I and II (p < 0.001). Pulmonary capillary wedge pressure in Group I was lower than those in Groups II and III (p < 0.05, p < 0.001). As shown in Fig. 1, however, we could not predict the values of cardiac index, stroke volume index and pulmonary capillary wedge pressure at the end-point of the exercise from the resting values of these hemodynamic parameters in each patient.

**RESULTS**

The hemodynamic and angiographic studies were completed without incident. Sixty-eight of 82 patients (83.9%) stopped exercise test due to leg fatigue, 5 (6.1%) due to dyspnea and 9 (11.0%) due to marked elevation of blood pressure. Figure I shows the mean pulmonary capillary wedge pressure (PCWP) and cardiac index (CI) at rest and at the end-point of the

<table>
<thead>
<tr>
<th>Table I HEMODYNAMICS AT REST IN EACH GROUP</th>
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<tbody>
<tr>
<td><strong>Group</strong></td>
</tr>
<tr>
<td>I (20 patients)</td>
</tr>
<tr>
<td>II (32 patients)</td>
</tr>
<tr>
<td>III (30 patients)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Group</strong></th>
<th><strong>CI</strong></th>
<th><strong>SVI</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>3.20 ± 0.16</td>
<td>43.3 ± 1.2</td>
</tr>
<tr>
<td>II</td>
<td>3.00 ± 0.13</td>
<td>41.5 ± 1.4</td>
</tr>
<tr>
<td>III</td>
<td>2.30 ± 0.09</td>
<td>34.1 ± 1.7</td>
</tr>
</tbody>
</table>

Values are mean ± SE. Abbreviations: HR = heart rate (beats/min), MAP = mean arterial pressure (mmHg), RPP = rate pressure product (x 10⁻²), a-v DO₂ = arterio-mixed venous oxygen difference (ml/100 ml), CI = cardiac index (L/min/m²), SVI = stroke volume index (ml/m²), PCWP = pulmonary capillary wedge pressure (mmHg). **p < 0.05, ***p < 0.001

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TABLE II  HEMODYNAMICS AT THE END-POINT OF THE EXERCISE IN EACH GROUP

<table>
<thead>
<tr>
<th>Group</th>
<th>HR</th>
<th>MAP</th>
<th>RPP</th>
<th>a-vDO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (20 patients)</td>
<td>126.8 ± 3.3</td>
<td>120.0 ± 5.0</td>
<td>234.4 ± 14.3</td>
<td>9.9 ± 0.4</td>
</tr>
<tr>
<td>II (32 patients)</td>
<td>126.6 ± 3.3</td>
<td>126.6 ± 3.3</td>
<td>231.1 ± 10.0</td>
<td>10.6 ± 0.4</td>
</tr>
<tr>
<td>III (30 patients)</td>
<td>116.0 ± 3.3</td>
<td>111.4 ± 3.3</td>
<td>194.1 ± 10.0</td>
<td>10.4 ± 0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Group</th>
<th>CI</th>
<th>SVI</th>
<th>PCWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>6.80 ± 0.45</td>
<td>53.3 ± 3.3</td>
<td>11.0 ± 0.9</td>
</tr>
<tr>
<td>II</td>
<td>6.30 ± 0.22</td>
<td>50.4 ± 1.7</td>
<td>21.6 ± 0.8</td>
</tr>
<tr>
<td>III</td>
<td>3.80 ± 0.15</td>
<td>32.9 ± 1.7</td>
<td>26.6 ± 1.3</td>
</tr>
</tbody>
</table>

Value are mean ± SE. Abbreviations: * = p < 0.05, ** = p < 0.01, *** = p < 0.001.
Other abbreviations are the same as Table I.

TABLE III  CLINICAL FEATURES IN 82 PATIENTS WITH MYOCARDIAL INFARCTION

<table>
<thead>
<tr>
<th>Group</th>
<th>Age (yrs)</th>
<th>Sex</th>
<th>Prior MI</th>
<th>Infarct</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (20 patients)</td>
<td>47.7 ± 2.0</td>
<td>M = 19, F = 1</td>
<td>(+) = 2, (−) = 18</td>
<td>(−) = 14</td>
<td>4</td>
</tr>
<tr>
<td>II (32 patients)</td>
<td>55.9 ± 1.7</td>
<td>M = 30, F = 2</td>
<td>(+) = 1, (−) = 31</td>
<td>(−) = 16</td>
<td>15</td>
</tr>
<tr>
<td>III (30 patients)</td>
<td>58.1 ± 1.7</td>
<td>M = 25, F = 5</td>
<td>(+) = 7, (−) = 23</td>
<td>(−) = 15</td>
<td>8</td>
</tr>
</tbody>
</table>

Abbreviations: M = male, F = female, A = anterior, I = inferior

Left Ventricular Function during Exercise and Exercise Tolerance

A duration of exercise (exercise tolerance) in Group I was 11.9 ± 0.5 (SEM) min, 10.6 ± 0.4 in Group II and 7.8 ± 0.5 in Group III (Fig. 2). Thus, exercise tolerance in Group I was larger than those in Groups II and III (p < 0.05, p < 0.001) and exercise tolerance was closely correlated to the left ventricular function during exercise.

Factors Determining Left Ventricular Function during Exercise

Clinical profiles in each group are shown in Table III. Mean age in Group I was 47.7 ± 2.0, 55.9 ± 1.7 in Group II and 58.1 ± 1.7 in Group III. Thus, patients in Group I was younger than those in Groups II and III (p < 0.01). No significant difference in sex population among three groups was observed. Seven of 30 patients (23.3%) in Group III, one of 32 patients (3.1%) in Group II and 2 of 20 patients (10.0%) in Group I had prior myocardial infarction. Patients in Group III were more frequently associated

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TABLE IV  CORONARY ARTERY LESION IN EACH GROUP

<table>
<thead>
<tr>
<th>Group</th>
<th>OVD</th>
<th>SVD</th>
<th>DVD</th>
<th>TVD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>7 (35.0)</td>
<td>12 (60.0)</td>
<td>0 ( )</td>
<td>1 ( 5.0)</td>
</tr>
<tr>
<td>Group II</td>
<td>4 (12.5)</td>
<td>23 (71.9)</td>
<td>5 (15.7)</td>
<td>0 ( )</td>
</tr>
<tr>
<td>Group III</td>
<td>1 ( 3.3)</td>
<td>8 (26.7)</td>
<td>18 (60.0)</td>
<td>3 (10.0)</td>
</tr>
</tbody>
</table>

The percentage is shown in the parenthesis.
Abbreviations: OVD = no significant coronary artery lesion, SVD = single vessel disease, DVD = double vessel disease, TVD = triple vessel disease

with prior myocardial infarction than those in Groups I and II (p < 0.001). No significant difference in hemodynamic responses to exercise between anterior and inferior infarction was found.

Relation between Hemodynamic Response to Exercise and Angiographic Findings
There were significant (≥ 75%) narrowing of luminal diameter of one or more coronary arteries in 70 of 82 patients (85.4%) (Table IV). Nineteen of 20 patients (95.0%) in Group I had no significant coronary artery lesion or single vessel disease and only one patient had triple vessel disease. On the other hand, in Group III, except one patient, all patients had at least one significant coronary artery lesion and 21 of 30 patients (70.0%) had multiple vessel disease.

Relation between Hemodynamic Response to Exercise and Infarct Size
In 50 patients who had a single myocardial infarction, we estimated infarct size from serial serum enzyme determinations and studied the relationship between infarct size and hemodynamic responses. Mean total CPK released in Group I was 886.2 ± 102.6 IU/ml, 1162.8 ± 82.2 in Group II and 1226.6 ± 134.1 in Group III (Fig. 3). Infarct size in Group III was significantly larger than that in Group I (p < 0.05).

DISCUSSION
Although there are a number of proposals for a rehabilitation program of physical activity in patients with myocardial infarction, there is no valuable guideline for physical activity after discharge. To establish the guideline for physical activity after discharge, it is necessary to assess the left ventricular performance during exercise. Exercise stress test is a useful method to evaluate cardiac functional reserve, and thus, has been widely performed. However, only a few reports concerning the hemodynamic responses to exercise are found in the literature. This study was undertaken to assess the hemodynamic responses to exercise and evaluate the left ventricular function at the end-point of the exercise in patients with myocardial infarction.

Validity of This Method
For the assessment of hemodynamic responses to the exercise test in patients with myocardial infarction, the following factors, which may be considered influences on hemodynamic responses to exercise, must be considered: 1) the intervals between the onset of myocardial infarction and the exercise test and 2) the reasons of discontinuation of the exercise test.

By the difference in the interval between the onset of myocardial infarction and the exercise test the evolution of myocardial infarction, coronary circulation such as the development of...
collateral vessels or the training effects during exercise may differ and these factors are considered influences on the hemodynamic responses to the exercise test. In our study, the exercise test was performed about 2 months after the onset of myocardial infarction before discharge. Thus, the influence of this interval on hemodynamic responses to exercise could be neglected.

Some investigators have reported that when anginal pain occurred during exercise test in patients with angina pectoris, pulmonary capillary wedge pressure markedly elevated and cardiac output decreased. These reports suggest that anginal attack influences on hemodynamic responses to exercise. In our present series, patients who stopped the exercise test due to the occurrence of chest pain were all excluded. Thus, the influence of anginal attack on hemodynamic response to exercise could also be ignored.

**Left Ventricular Function during Exercise and Exercise Tolerance**

We analyzed the relationship between left ventricular function at the end-point of the exercise test and exercise tolerance, and the latter may be considered a useful index of the former in patients with myocardial infarction during exercise. Malmberg et al. performed the exercise test on patients with coronary heart disease and reported a positive correlation between exercise tolerance and an increase in stroke volume index during exercise. This finding is in agreement with the present results.

**Factors Determining Left Ventricular Function during Exercise in Patients with Myocardial Infarction**

**Age, Sex and Previous Myocardial Infarction**

Mean age in Group I was younger than those in Groups II and III (p < 0.01) and left ventricular function during exercise in younger patients with myocardial infarction was better than that in older patients. There was no significant difference in left ventricular function during exercise between female and male. Left ventricular function during exercise in patients with previous myocardial infarction was more deteriorated than that in those without previous infarction. One of the reasons for this findings is that the present infarct size in patients with prior infarction was a summation of old infarct and new infarct, and thus, the combined infarct size may be larger than that in a single infarction. Another reason may be that the severity of coronary artery lesions in patients with prior infarction is more severe than that in those without prior infarction.

**Coronary Artery Lesion**

In our series, we observed an inverse correlation between left ventricular function at the end-point of the exercise and the severity of coronary artery lesions which may be considered one of the important factors determining left ventricular performance in patients with myocardial infarction.

Malmberg et al. have reported that while there were no significant differences in hemodynamic responses to exercise between patients with coronary heart disease without significant coronary artery lesions or with single vessel disease and those with multiple vessel disease, mean pulmonary venous pressure in patients with multiple vessel disease was higher than that in those with single vessel disease. Saltups et al. have also reported that in patients with coronary artery disease the severity of coronary artery lesions was closely related to the level of left ventricular end-diastolic pressure at the end-point of the exercise using a bicycle ergometer in the supine position. These reports strongly suggest that exercise-induced myocardial ischemia influences on left ventricular function in patients with myocardial infarction.

Williamson et al. also performed exercise test using a bicycle ergometer in patients with myocardial infarction and observed that patients with coronary artery disease had a normal stress work index response before the occurrence of ischemia, but their left ventricular functional curve shifted abruptly to a worse ventricular functional curve when ischemia occurred.

**Infarct Size**

The infarct size in Group III was significantly larger than that in Group I, indicating that the infarct size is one of the factors contributing to left ventricular function during exercise. In patients with a large infarct size, left ventricular function should deteriorate. Furthermore, a large infarction is often associated with severe abnormal left ventricular wall movement. Bleifeld et al. have reported an inverse correlation between infarct size and left ventricular function in the acute phase of myocardial infarction. Feild et al. calculated abnormally contracting segments (ACS) as the ratio of the extent of asynergy to the circumference length.
obtained from an end-diastolic left ventriculogram in patients in the chronic stage of myocardial infarction. They observed an inverse correlation between the extent of ACS and the ejection fraction. Although these results were obtained at rest and we cannot estimate them on the same level as those during exercise, infarct size is probably one of the important factors contributing to left ventricular function during exercise.

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