Reproducibility of exercise tests in patients with symptomatic ischaemic heart disease

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In 50 patients with ischaemic heart disease prospective analyses of the reproducibility of exercise tests at 3-month intervals were performed. The same method of testing was used repeatedly in a smaller group of patients 3 or more times at 6- to 8-week intervals.

No significant differences were found in maximal heart rate, maximal systolic blood pressure, rate-pressure product, and total work. Symptoms resulting in the discontinuation of exercise were unchanged in 94 per cent of patients. The evaluation of the electrocardiographic recordings revealed good agreement in ST segment depression and ST segment elevation. The reproducibility of arrhythmic events was very poor.

The standardized electrocardiographic exercise test is, therefore, recommended for objective evaluation of various interventions in patients with manifest ischaemic heart disease, both in short-term and long-term follow-up studies.

Exercise electrocardiography is increasingly used for assessing cardiovascular performance in patients with cardiac disease. Reproducibility of this method of assessment is essential for a valid interpretation of the results in repeated investigations after various therapeutic procedures. Good short-term reproducibility of various indices characterizing physical working capacity has been found in healthy subjects and in the majority of patients with ischaemic heart disease investigated repeatedly at intervals of a few minutes up to several weeks, either without any interference or after administering placebo (Borg and Dahlström, 1962; Bruce et al., 1963; Hamer et al., 1966; Hallén, 1964; Robinson, 1967, 1968; Dagenais et al., 1969; Dagenais, Pitt, and Ross, 1971; Ellestad et al., 1969; Arnonow and Chesluk, 1970; Redwood et al., 1971; Sime et al., 1972; Smokler et al., 1973). Doan et al. (1966) found excellent long-term reproducibility of electrocardiographic signs of myocardial ischaemia in asymptomatic men.

As results of therapeutic procedures such as surgical revascularization and training programmes after myocardial infarction cannot be evaluated until after a considerable time has elapsed, we decided to study the reproducibility of exercise electrocardiography after an interval of 3 months in patients with stable manifest ischaemic heart disease.

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Patients and methods

A group of 50 patients with stable manifest ischaemic heart disease, with angina and/or definite myocardial infarction (according to criteria recommended by a W.H.O. Working Group, 1969), was studied. All were candidates for bypass surgery or long-term rehabilitation programmes. Subjects suffering from heart failure, hypertension, intermittent claudication, and rhythm or conduction disturbances during daily activities, or musculoskeletal disease limiting exercise performance were not included in this study. At least 6 weeks before the test, treatment with digitalis, diuretics, hypotensives, and beta-blocking agents was stopped. To eliminate patients with very low physical working capacity, a minimum of 100 beats/min during exercise was required. No changes in the patients' physical and social activities, diet, or medication were made between the repeated tests. The exercise tests were carried out in the sitting position on a bicycle ergometer (Elema Schönander) at least 2 hours after the last meal, drinking coffee or strong tea, smoking, or administration of nitroglycerin. Lowest load and increments in load were adjusted to the circulatory and physical capacity of each subject as measured in previous examinations before the start of the study. Each load was kept constant for 4 minutes, subsequent loads being increased so as to reach 75 per cent of maximal aerobic power or limiting symptoms during the second or third level of work. Exercise was terminated if the patient developed electrocardiographic abnormalities and/or limiting symptoms and signs according to a W.H.O. Working Group recommendation (1971). Maximal heart rate (beats/min), maximal systolic blood pressure (mmHg), rate-pressure...
product divided by 100 and expressed in arbitrary units, total work in kpm, limiting symptoms, and electrocardiographic abnormalities were analysed at the beginning and at the end of the study in all patients. In a smaller sub-group (7 patients) repeated examinations 3 to 5 times at intervals of 6 to 8 weeks were performed. Statistical analysis used t-test, correlation, and regression equations.

**TABLE I Reproducibility of maximal heart rate, maximal systolic blood pressure, rate-pressure product, and total work during submaximal exercise tests in 50 patients with ischaemic heart disease**

<table>
<thead>
<tr>
<th>Test</th>
<th>Heart rate (beats/min)</th>
<th>Systolic blood pressure (mmHg)</th>
<th>Rate-pressure product (units)</th>
<th>Total work (kpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Mean</td>
<td>134.4</td>
<td>135.8</td>
<td>176.5</td>
<td>176.6</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>20.8</td>
<td>18.9</td>
<td>23.1</td>
<td>23.4</td>
</tr>
<tr>
<td>Mean difference</td>
<td>+1.4</td>
<td>+0.1</td>
<td>2.22</td>
<td>3.4</td>
</tr>
<tr>
<td>r</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Technical error of measurement</td>
<td>5.2</td>
<td>9.4</td>
<td>14.4</td>
<td>672.7</td>
</tr>
</tbody>
</table>

**FIG. 1** Reproducibility of maximal heart rate, maximal systolic blood pressure, rate-pressure product, and total work during submaximal exercise tests in 50 patients with ischaemic heart disease. The results of the first test were plotted on the abscissa and the results of the second test on the ordinate.
Results

Differences in exercise test after 3 months without medical intervention
Mean values and results of statistical analysis for maximal heart rate, maximal systolic blood pressure, rate-pressure product, and total work are summarized in Table 1. The regression equations and regression lines are given in Fig. 1.

Maximal heart rate
There was an increase of the mean maximal heart rate of 1.4 beats/min in the second test compared to the first one. There was no significant difference between the repeated tests.

Maximal systolic blood pressure
There was an increase of the mean maximal systolic blood pressure of 0.1 mmHg in the second test compared to the first one. There was no significant difference between repeated tests.

Rate-pressure product
There was an increase of the mean rate-pressure product of 2.22 units in the second test compared to the first one. There was no significant difference between the repeated tests.

Total work
There was a decrease of the mean total work of 1 kpm in the second test compared to the first one. There was no significant difference between the repeated tests.

Limiting symptoms (Table 2)
The first exercise test had to be discontinued because of angina pectoris in 35 (70%) and dyspnoea in 15 (30%) patients. In 47 patients (94%), the reasons for discontinuing the repeated test were identical. Only 3 patients (6%) stopped the first exercise because of angina and the second one because of dyspnoea.

Electrocardiographic signs (Table 2)
During the first test horizontal ST segment depressions were found in 37 patients (74%), ST segment elevations in 6 (12%), and onset of arrhythmias in 7 (14%). During the repeated test ST segment depressions were present in 36 out of the 37 patients (97% agreement), ST segment elevations were observed in all 6 patients (100% agreement), but the onset of identical arrhythmia in only 1 out of 7 patients (agreement in 14%). In the whole group identical electrocardiographic abnormalities were found in 43 out of 50 patients (agreement 86%).

Results of exercise tests repeated 3 to 5 times
The results in 7 patients are shown in Table 3 and Fig. 2. The variability of maximal heart rate, maximal systolic blood pressure, rate-pressure product, and total work were similar to the variability obtained between the two tests in the 50 patients. The symptoms and electrocardiographic signs at maximal heart rate were mostly identical also in this group.

Discussion
Our results show good reproducibility of exercise tests repeated at longer intervals. Similar findings have been reported also by others (Hallén, 1964; Mason et al., 1967; Robinson 1967, 1968; Ellestad et al., 1969; Dagenais et al., 1969, 1971; Smokler et al., 1973). However, these authors tested reproducibility over much shorter periods, and mostly used only some of the criteria we employed.

The long-term reproducibility of exercise tests depends on the spontaneous course of the disease which limits the physical activity of the patient. A good correlation between repeated tests can be expected only in a relatively stable phase of the disease. Any change in the clinical features may not only affect the results but, in some cases (e.g. unstable angina pectoris, recent onset of arrhythmia, acute myocardial infarction), may be a contra-indication for exercise testing.

| TABLE 2 | Reproducibility of symptoms and electrocardiographic signs of myocardial ischaemic response to submaximal exercise tests in 50 patients |
| Symptons | Angina pectoris | 32 | 3 |
| | Dyspnoea | 15 | 0 |
| Electrocardiographic abnormalities | ST depression (11) | 36 | 1 |
| | ST elevation (16) | 6 | 0 |
| | Arrhythmias (15) | 1 | 6 |

Figures in parentheses are items of the Minnesota code.
Multiple exercise tests are frequently performed in a single patient to evaluate various therapeutic measures. It has been suggested that variations from one test to the other could be caused by adaptation or the training effect (Erickson et al., 1946; Hamer et al., 1966; MacAlpin and Kattus, 1966; Robinson, 1968; Smokler et al., 1973). A part of our study was designed to evaluate this effect. A small group of patients was tested 3 or more times at 6- to 8-week intervals. The variations found were within the limits of the good reproducibility shown in 50 patients tested on 2 separate occasions. These results are consistent, and in agreement with the findings of others (Hallen, 1964; Dagenais et al., 1969; Redwood et al., 1971) who could not find a significant difference between repeated tests at shorter intervals.

A standard protocol is a fundamental requirement for reasonable reproducibility of the test. It is well known that the use of different loads or various
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in 7 patients tested for submaximal work capacity 3 or more times at 6- to 8-week intervals

<table>
<thead>
<tr>
<th>Total work (kpm)</th>
<th>Symptoms</th>
<th>Electrocardiographic abnormalities (Minnesota code)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3 4 5</td>
<td>1 2 3 4</td>
</tr>
<tr>
<td>2400</td>
<td>3000 2400</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>2400</td>
<td>2400 2400</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>2400</td>
<td>2400 2400</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>450</td>
<td>450 450</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>1350</td>
<td>1800 1350</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>5100</td>
<td>5100 5100</td>
<td>Angina pectoris</td>
</tr>
<tr>
<td>4200</td>
<td>420 3300</td>
<td>Angina pectoris</td>
</tr>
</tbody>
</table>

types of work in a single patient may change the angina threshold (Wahren and Bygdeman, 1971; Lecerf, 1971). However, Robinson (1967) showed that even during exercise of various types and severity angina could be consistently related to the work level reached as measured by the product of heart rate and systolic blood pressure corrected for changes in ejection time. The precise measurement of ejection time during exercise requires an intraarterial tracing which is not always practicable for a patient tested repeatedly. Yet even this technique does not eliminate discrepant results if different and particularly high initial exercise loads are employed (Redwood et al., 1971). We conclude that the standard protocol is of utmost importance for good long-term reproducibility of the exercise tests. This, in turn, makes objective evaluation of therapeutic intervention possible.

References


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