Low-level exercise testing after myocardial infarction: usefulness in enhancing clinical risk stratification*

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ABSTRACT Of 886 patients enrolled in our multicenter study, 667 performed a low-level exercise test early after myocardial infarction, most before discharge. Excluding seven patients who died before the test could be considered, there was a 14% 1 year cardiac mortality in 192 patients who did not take the test (150 for medical and 42 for logistic reasons) compared with 5% in those who did (p < .0001). Of those who took the test, 12% subsequently underwent bypass graft surgery compared with 14% of those who did not (p > .05). Decreased mortality in the year after the infarction in those taking the test was associated with an increase in blood pressure to 110 mm Hg or higher (3% vs 18%; p < .001), ability to complete the 9 min test (3% vs 8%; p < .01), and the absence of couplets (4% vs 13%; p < .05) or any ventricular ectopic depolarizations (4% vs 7%; p < .05) before, during, or after exercise. Achievement of a blood pressure of 110 mm Hg or higher during exercise in patients with no evidence of pulmonary congestion on the chest x-ray identified a group of 454 patients (70% of those taking the test) with a 1 year cardiac mortality of 1% compared with 13% in the remaining patients (p < .0001). Logistic models showed that the exercise test contributed independent prognostic information for cardiac death, new infarction, and bypass surgery. Results of low-level exercise testing before hospital discharge combined with clinical features of the infarction can effectively identify patients at low risk for subsequent cardiac mortality.


EXERCISE TESTING early after a myocardial infarction has been advocated to establish prognosis,1-12 to identify patients likely to have particularly unfavorable coronary anatomy who might benefit from aggressive diagnostic and therapeutic measures, and to identify those at "low risk" in whom such efforts are unnecessary.17 However, the ability of specific variables, such as ST segment depression or angina elicited during the test, to predict new events is uncertain since somewhat divergent results have been reported in the different study populations. In addition, only a few studies have combined the results of exercise testing with the clinical information available during the hospitalization to develop prognostic stratification.18,19

To confirm the results of these smaller studies in a large heterogeneous group and to further refine the risk-stratification of patients after infarction, exercise testing was performed as part of a large multicenter postinfarction study of prognosis after myocardial infarction (MPIP).20 It was anticipated that the large heterogeneous patient population drawn from nine centers across the United States would permit a generally applicable evaluation of the findings from the earlier, mostly smaller studies from single institutions. We also planned to evaluate whether the exercise test added prognostic information above and beyond that which was already known from the available clinical and demographic information. Although radionuclide ventriculography and 24 hr Holter monitoring were used in the initial risk stratification,20 the results of these tests...
were not considered in this study in order to permit evaluation of the low-level exercise test exclusive of other expensive stratifying tests.

Methods

Patients under 70 years of age who were discharged from the coronary care unit after an acute myocardial infarction were eligible for enrollment. Patients were excluded from enrollment if they had life-threatening comorbidity or if follow-up could not be arranged. From January 1, 1979, to December 31, 1980, 1417 patients met the eligibility requirements at nine participating hospitals, and 866 patients consented to enrollment. A total of 853 patients were followed for 1 year. Approximately 45% of the patients were enrolled from three participating hospitals in New York City, 26% from three hospitals in Tucson, 15% from two hospitals in St. Louis, and 14% from one hospital in Rochester, NY. Trained enrolling personnel interviewed the patients and reviewed their records during the hospitalization.

The diagnosis of definite acute myocardial infarction required two of the following: (1) a history of central chest discomfort lasting 30 min or more, (2) electrocardiographic Q waves that fulfilled one of the abnormal Q wave criteria of the Minnesota Code\textsuperscript{24} with evolutionary ST and T wave changes on serial tracings, and (3) MB isoenzyme fraction greater than 45% of total creatinine kinase, or creatine kinase or aspartate transaminase elevation greater than the upper limit of normal for the hospital laboratory, for a minimum of 2 days after the clinical symptoms without other reasons for the elevation. Two hundred sixty-three patients met only the chest discomfort and enzyme criteria, and not the electrocardiographic criteria. Patients were followed by clinic visit or telephone at 3, 6, and 12 months after infarction. All but 13 patients were followed for at least 1 year.

During the follow-up period, 63 new fatal and nonfatal myocardial infarctions were verified by hospital records and met the same criteria as the qualifying infarctions. Nineteen patients who died did not meet all criteria but were judged by the MPIP Mortality Committee to have suffered a probable new myocardial infarction and were combined with the 63 patients for the total group of 82 new myocardial infarctions in the year after the infarction. Infarctions occurring as the result of a cardiac procedure (bypass surgery or coronary angioplasty) were considered procedure-related and were not included as new infarctions.

The procedures followed in classifying each death have been previously described. An independent MPIP Mortality Committee reviewed each death and categorized it according to its presumed underlying cause. Cardiac deaths due to atherosclerotic heart disease were used as end points in the analyses.

Exercise testing. Of the 866 patients enrolled in the study, 841 were deemed capable of walking on the treadmill and were asked to perform the exercise test (18 patients had neuromuscular or peripheral vascular problems and seven died before the test could be considered). Fifteen patients refused because they were afraid of the test and 11 were not interested. Sixteen patients who agreed were unable to perform the test for logistic reasons. One hundred patients were advised against participation by their physicians. Physicians were not required to state the reasons for excluding their patients from the test, but the reasons included those listed below plus a general unwillingness to "submit" their patients to the perceived risk of the test. Thirty-two patients were additionally excluded by study personnel because of unstable angina, persistent rales involving more than the lower third of the lung fields, or inability to walk unaided 100 feet to the treadmill. Overall, of the 866 patients enrolled in the study, 667 patients (77%) took the low-level treadmill exercise test and 199 did not. The reasons for failure to take the test and the cardiac mortality in the subgroups are shown in figure 1.

The treadmill protocol has been described previously.\textsuperscript{12} The grade was 0% for 3 min, 5% for the next 3 min, and 10% for the final 3 min. After 1 min at 1 mph the speed was increased to 1.7 mph for the final 8 min. The final 3 min were identical to stage I of the Bruce protocol. The duration of the test was 9 min, but it was terminated early if the patient felt uncomfortable and wished to stop, if there was any decrease in blood pressure, if there was ST segment depression of 4 mm, or if the heart rate exceeded 150 beats/min.

A total of 187 patients (28%) were taking digoxin and 207 patients (31%) were taking a \( \beta \)-blocker (200 propranolol, seven metoprolol) at the time of the test. Forty patients were taking both medications and 313 were taking neither. No effort was

\textbf{FIGURE 1.} Reasons for not taking the exercise test. "Excluded for medical reasons" comprises patients who were excluded from the test by their physicians (100 patients) and patients excluded by the physician supervising the exercise test after examination (32 patients). Patients who could not walk included persons with orthopedic and neurologic problems. Patients who refused were otherwise eligible to take the test. Logistic reasons included eligible persons who had agreed to exercise but were unable to do so.
made to withhold medication before the test. All end points were evaluated for the group as a whole and then for the subgroups with and without \( \beta \)-blockers and with and without digitals because of the possible influence of these drugs on the results of exercise testing.

Blood pressure was recorded at 1 min intervals with a standard arm cuff. Electrocardiographic leads V\(_2\), V\(_3\), and V\(_6\) were recorded with patients supine and standing before the test, at 1 min intervals during the test, at maximum exercise, and with patients supine at 1, 3, 6, and 9 min after discontinuation of exercise. These leads were chosen to standardize the test over all the enrolling centers. ST segment displacement was measured 0.06 sec after the J point. The maximum ST displacement (to the nearest 0.5 mm) and the ST slope (horizontal, upsloping, or downsloping) were recorded at rest, maximum exercise, and recovery for each lead. The supine recovery records were compared with the supine pretest records, and the exercising records were compared with the standing pretest records. Significant ST segment depression was defined as horizontal or downsloping displacement greater than 1 mm compared with the corresponding resting tracing. The ST segments from patients with left bundle branch block were not interpreted, but patients with right bundle branch block were included in this analysis.

The electrocardiogram was printed out continuously for 9 min before exercise, during the exercise test, and for 9 min after the test to count the total number and type of ectopic beats. Ventricular ectopic depolarizations (VEDs) and supraventricular ectopic depolarizations were counted during each of the three recording periods, a maximum of 27 min. "Couplets" were defined as two consecutive VEDs at any rate, and "runs" were defined as three or more VEDs in a row.

**Quality control.** Completed data forms were scrutinized for errors by two data clerks. An extensive computer edit was undertaken before data were entered into a specially designed archival data management system on an IBM 3032 computer. Ten percent of the data in the file was checked against the original data forms and a negligible number of discrepancies were found. For each variable, the five highest and five lowest values were checked for spurious values, and individual patient data were displayed before being included in the database.

The exercise electrocardiograms were interpreted at each enrolling center. To ensure uniformity of ST segment data interpretation, samples of tracings from each center were overread by the authors at a joint meeting.

**Data analysis.** The hypothesis at the onset of the study was that the exercise test would identify patients with potentially ischemic ("jeopardized") myocardium after the myocardial infarction who would be at risk for new ischemic events. We evaluated time on the treadmill (workload performed), 2, 3, 7, 12, 21 development of angina during or after exercise, 2, 5, 6, 9, 11, 12, 15 maximum blood pressure attained during exercise, 12 ST segment depression, 2, 3, 5, 6, 10-15 ST segment elevation, 16 and development of arrhythmias 2, 12 with a univariate analysis using Fisher's exact test of probability against these end points for the year after the infarction: cardiac death, new myocardial infarction, and coronary artery bypass surgery. These end points were not mutually exclusive.

A stepwise logistic regression procedure 23 was performed on the exercise and clinical variables, and multivariate logistic regressions were performed on the clinical and exercise variables found to be significant in the stepwise analyses. The rank correlations between predicted probability and response for these models and the multiple logistic model performed with only the selected clinical variables were compared. The significance of the contribution of the exercise variables to the prediction of a given end point was calculated by subtracting the chi squares of the clinical features model from the combined model.

For this analysis we used age, New York Heart Association class, the degree of pulmonary congestion on chest x-ray, extensiveness of rales on the physical examination, and amount of ST segment depression on the qualifying electrocardiogram as ranked variables. A total of 622 patients had all the features evaluated and their data were entered into the model. The rank correlation between predicted probability and response for each model was used as an index of the ability of the model to predict the end point.

**Results**

**Patients.** The 667 patients who took the exercise test had a higher prevalence of features that have been associated with a good prognosis after a myocardial infarction than the 192 who did not take the test (excluding the seven patients who died before the test could be considered) (table 1). Not surprisingly, there was a higher cardiac mortality in the year after the infarction in the group that did not take the exercise test (p < .0001; table 2). Thus the ability to perform the exercise test (absence of any of the exclusions, physician and patient approval, plus the ability to walk 100 feet unaided) immediately defined a moderately low-risk group for mortality in the year after the myocardial infarction.

The test was performed a mean of 14.8 days (range 5 to 57) after hospital admission; 423 patients performed the test by 14 days after hospital admission and 532 (80%) performed the test by 18 days. There were no

**TABLE 1**

Clinical features of patients taking the low-level exercise test

<table>
<thead>
<tr>
<th>Feature</th>
<th>No EXT(^a) n = 192 (%)</th>
<th>EXT(^b) n = 667 (%)</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age under 60 yr</td>
<td>45.8</td>
<td>59.8</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Men</td>
<td>70.8</td>
<td>79.5</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>First MI</td>
<td>71.7</td>
<td>77.9</td>
<td>NS</td>
</tr>
<tr>
<td>Non-Q-wave MI</td>
<td>19.8</td>
<td>21.7</td>
<td>NS</td>
</tr>
<tr>
<td>Anterior MI(^c)</td>
<td>45.3</td>
<td>30.9</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Inferior MI(^d)</td>
<td>30.7</td>
<td>42.4</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>NYHA class I (1 mo before admission)</td>
<td>50.0</td>
<td>66.0</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Resting heart rate &lt;90 bpm</td>
<td>70.8</td>
<td>79.6</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>No rales above bases(^e)</td>
<td>77.6</td>
<td>88.6</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>No pulmonary congestion on chest x-ray(^f)</td>
<td>64.0</td>
<td>75.3</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>No ST depression on qualifying ECG</td>
<td>72.1</td>
<td>81.9</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>Ejection fraction &gt;35%</td>
<td>65.5</td>
<td>73.3</td>
<td>&lt;.05</td>
</tr>
</tbody>
</table>

\(n = 174\) \(n = 633\)

\(^a\)Excludes seven patients who died before exercise test could be considered.

\(^b\)Two-tailed Fisher's exact test.

\(^c\)Refers to most recent infarction.

\(^d\)Upon admission to the cardiac care unit.
TABLE 2
Relationship of taking exercise test to end points

<table>
<thead>
<tr>
<th>End point</th>
<th>No EXT (^a) (n = 192)</th>
<th>EXT (n = 667)</th>
<th>p value (^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total mortality (^c)</td>
<td>32 17</td>
<td>38 6</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Cardiac mortality (^c)</td>
<td>27 14</td>
<td>31 5</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>Bypass surgery (^d)</td>
<td>27 14</td>
<td>75 12</td>
<td>NS</td>
</tr>
<tr>
<td>New MI</td>
<td>24 13</td>
<td>57 9</td>
<td>&lt;.05</td>
</tr>
<tr>
<td>Angiography (^e)</td>
<td>39 20</td>
<td>156 23</td>
<td>NS</td>
</tr>
</tbody>
</table>

EXT = exercise test; New MI = reinfarction within 1 year follow-up (includes both fatal and nonfatal reinfarctions).

\(^a\)Excludes seven patients who died before exercise test could be considered.

\(^b\)Two-tailed Fisher’s exact test. NS = p > .05.

\(^c\)Deaths in each category in 1 year.

\(^d\)Performance of bypass graft surgery in 1 year follow-up.

\(^e\)Underwent coronary angiography within 6 months of infarction.

Deaths or infarctions as a result of the procedure. Two patients were admitted to the coronary care unit after the test, one because of angina and one because of congestive failure, but neither suffered lasting sequela.

A total of 398 patients completed the full 9 min test (60%). The most common reasons for stopping before completion (more than one reason could be given) were fatigue (122 patients, 18%) and angina (74 patients, 11%). Nine patients were stopped for a heart rate greater than 150 beats/min. The 1 year cardiac mortality in the patients who stopped for angina, dyspnea, fatigue, or dizziness ranged from 11% to 15%, with p < .05 in each case when compared with all patients lacking this symptom. Eighteen patients stopped because of arrhythmias, but the difference in 1 year cardiac mortality (11% vs 3% in those without arrhythmias) was not statistically significant. Marked ST segment elevation (>5 mm) was seen in only six patients, of whom two died. The cardiac mortality in the 24 patients who stopped because of the development of hypotension (a fall to <90 mm Hg or 80% of baseline during exertion) was no higher (9% 1 year cardiac mortality) than for other patients who could not complete the test. Thirty-seven patients did not complete the test for noncardiac reasons, and of this group one patient (3%) suffered a cardiac death in the year after the infarction.

Prognostic value of selected exercise parameters. The results of the analysis for cardiac death, new infarction, and bypass surgery within 1 year are seen in table 3. Of the 667 patients who took the exercise test, there were 31 cardiac deaths in the first year (5%), 57 new myocardial infarctions (10%), and 75 coronary bypass operations (12%).

ST segment changes. ST segment depression greater than 1 mm during or after exercise was not associated with cardiac death within 1 year or with development of new infarction but was strongly associated with bypass surgery (table 3). ST segment depression was selected as the first variable in the stepwise logistic model identifying patients likely to undergo subsequent bypass surgery and had the highest correlation with surgery of all variables considered in the model incorporating clinical and exercise variables (table 4). Bypass surgery was performed in 19% of patients with 1 mm or more of ST depression during or after exercise com-

TABLE 3
Exercise features vs end points

<table>
<thead>
<tr>
<th>Feature</th>
<th>n (of 667)</th>
<th>Cardiac mortality</th>
<th>New MI</th>
<th>Bypass surgery</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% +</td>
<td>% -</td>
<td>p value</td>
<td>% +</td>
</tr>
<tr>
<td>ST &gt;1 mm</td>
<td>167</td>
<td>4 5</td>
<td></td>
<td>8 9</td>
</tr>
<tr>
<td>ST &gt;2 mm</td>
<td>62</td>
<td>5 5</td>
<td></td>
<td>8 9</td>
</tr>
<tr>
<td>BP &lt;110 mm Hg</td>
<td>57</td>
<td>18 3</td>
<td>&lt;.001</td>
<td>16 7</td>
</tr>
<tr>
<td>HR &gt;119 bpm</td>
<td>202</td>
<td>8 4</td>
<td>&lt;.01</td>
<td>7 9</td>
</tr>
<tr>
<td>Angina</td>
<td>115</td>
<td>9 4</td>
<td>&lt;.05</td>
<td>13 8</td>
</tr>
<tr>
<td>EXT &lt;9 min</td>
<td>269</td>
<td>8 3</td>
<td>&lt;.01</td>
<td>12 6</td>
</tr>
<tr>
<td>Couplets</td>
<td>45</td>
<td>13 4</td>
<td>&lt;.05</td>
<td>13 8</td>
</tr>
<tr>
<td>Any VED</td>
<td>289</td>
<td>7 3</td>
<td>&lt;.05</td>
<td>9 8</td>
</tr>
<tr>
<td>SVED</td>
<td>157</td>
<td>7 4</td>
<td>&lt;.01</td>
<td>15 7</td>
</tr>
</tbody>
</table>

% + = percent of patients with the feature who have the end point; % - = percent of patients without the feature who have the end point; ST = ST segment depression; BP = blood pressure; HR = heart rate; EXT <9 min = duration on the treadmill less than 9 min; Any VED = any ventricular ectopic depolarizations during period of monitoring; SVED = supraventricular ectopic depolarizations during period of monitoring. Other abbreviations as in table 2.

\(^a\)Assessed 1 year after myocardial infarction.

\(^b\)Fisher’s exact test (value given only where p < .05).
TABLE 4
Stepwise logistic regressions — final models

<table>
<thead>
<tr>
<th>End point</th>
<th>Variables</th>
<th>Features</th>
<th>RR</th>
<th>( \chi^2 )</th>
<th>( p ) value</th>
<th>Model ( \chi^2 )</th>
<th>RC</th>
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<tbody>
<tr>
<td>Cardiac death</td>
<td>Clinical only</td>
<td>Pulm. congestion</td>
<td>4.0</td>
<td>26.12</td>
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<td></td>
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<td>HR ( \geq 90 ) bpm</td>
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<td>4.34</td>
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<td>Exercise only</td>
<td>BP ( &lt;110 ) mm Hg</td>
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<td>14.54</td>
<td>.0001</td>
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<td></td>
<td>2.7</td>
<td>4.94</td>
<td>.0262</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Exercise and clinical</td>
<td>Pulm. congestion</td>
<td>3.3</td>
<td>18.17</td>
<td>&lt;.0001</td>
<td>57.03</td>
<td>.689&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td></td>
<td>BP ( &lt;110 ) mm Hg</td>
<td>4.7</td>
<td>9.10</td>
<td>.0026</td>
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<td>Angina with test</td>
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<td>6.57</td>
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<tr>
<td>New infarction</td>
<td>Clinical only</td>
<td>Pulm. congestion</td>
<td>2.2</td>
<td>14.82</td>
<td>.0001</td>
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<td>.193</td>
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<td>9.23</td>
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<td>.195</td>
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<tr>
<td>Exercise and clinical</td>
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<td>11.99</td>
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<td>19.50</td>
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<td>6.91</td>
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<td>18.67</td>
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<td>HR ( &lt;90 ) bpm</td>
<td>2.3</td>
<td>4.00</td>
<td>.0456</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Exercise only</td>
<td>ST ( &gt;1 ) mm</td>
<td>2.2</td>
<td>8.62</td>
<td>.0033</td>
<td>17.28</td>
<td>.253</td>
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<td></td>
<td>Angina</td>
<td>1.9</td>
<td>4.90</td>
<td>.0269</td>
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<tr>
<td>Exercise and clinical</td>
<td>ST ( &gt;1 ) mm</td>
<td>2.0</td>
<td>6.83</td>
<td>.0090</td>
<td>30.35</td>
<td>.358&lt;sup&gt;c&lt;/sup&gt;</td>
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</tr>
<tr>
<td></td>
<td>Male</td>
<td>2.9</td>
<td>5.60</td>
<td>.0180</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>HR ( &lt;90 ) bpm</td>
<td>2.0</td>
<td>2.82</td>
<td>.0929</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Angina in hosp.</td>
<td>1.6</td>
<td>2.77</td>
<td>.0958</td>
<td></td>
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<tr>
<td></td>
<td>Angina during test</td>
<td>1.4</td>
<td>1.10</td>
<td>.2938</td>
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</tr>
</tbody>
</table>

RR = relative risk (risk with feature present/risk with feature absent) adjusted for other terms in the model = \( e^{b_{k}} \); RC = rank correlation between predicted probability and response; pulm. congestion = any pulmonary congestion on initial chest x-ray; HR = heart rate; \( \chi^2 \) = percentage points of chi square distribution. Other abbreviations as in table 3.

<sup>a</sup>\( p < .001 \) comparing the model with both clinical and exercise variables to the model with clinical variables alone.

<sup>b</sup>\( p < .05 \) comparing the model with both clinical and exercise variables to the model with clinical variables alone.

<sup>c</sup>\( p < .01 \) comparing the model with both clinical and exercise variables to the model with clinical variables alone.

pared with 9% of those who did not have this finding. ST segment depression did not correlate with new infarction. ST segment elevation was not associated with any of the end points.

We examined ST segment depression dichotomized at 0.5 and 2.0 mm and also looked at lead V₅ individually to determine whether the prognostic information was improved by segregating that lead from the other monitored leads, V₂ and aVF. The results were not different with any of these methods for the group as a whole. Two patients died among the 21 taking β-blockers who developed ST segment depression greater than 2 mm in any of the three monitored leads, compared with six of 186 who did not develop this end point for an odds ratio of 3.0. However, this did not reach statistical significance.

**Angina during or after exertion.** One hundred fifteen patients developed angina during or after the test and 10 (9%) died of cardiac causes in the first year compared with 21 of the 552 patients (4%) who did not have angina (table 3; \( p < .05 \)). Angina during or after the test was not significantly related to development of a new infarction but was strongly related to the performance of bypass graft surgery within the year (\( p < .001 \)). Twenty percent of patients who developed angina during the exercise test underwent bypass graft surgery compared with 9% of those without angina (\( p < .01 \)). These relationships were not influenced by drug administration. Angina during or after the exercise test had predictive value independent from that of ST segment changes, since it was selected in the stepwise logistic models for both cardiac death and bypass graft surgery, in the latter after adjustment for ST segment response. The likelihood of bypass grafting was greater in the presence of both angina during the test and ST segment depression (15/56, 27%) than in the presence of angina alone (8/59, 14%).

**Duration of exercise.** The duration of the test was inversely related to cardiac death within the year (table 3). In addition to looking at duration on the treadmill as
a continuous variable, we also looked at two “cut points”: the ability to complete the 9 min protocol and the ability to exercise more than 6 min (completing 1.7 mph at 5% grade). Cardiac death and the incidence of new infarction were equally related to both cut points. Duration of exercise was not related to the performance of bypass surgery. These relationships held when the patients were subgrouped by drug administration. When patients were subgrouped according to drug administration, the odds ratio of cardiac death to completion of the test was greater than 2 for patients whether or not they were taking digitalis at the time of the test, but \( p < .05 \) only for those not taking digitalis.

**Maximum systolic blood pressure attained.** The maximum systolic blood pressure attained during the stress test was related to cardiac mortality in the first year. Of the 57 patients who did not attain a blood pressure of 110 mm Hg, 10 (18%) suffered a cardiac death and nine (16%) had a new infarction in the first year (table 3). There was no relationship between maximum systolic blood pressure attained and performance of bypass surgery. These relationships were not influenced by the \( \beta \)-blockers or digitalis.

**Development of excessive heart rate.** A heart rate of 120 beats/min or greater was attained by 202 patients during the limited test, 17 of whom died within 1 year (8.4%) compared with 14 of the 464 (3%) whose heart rate did not exceed this threshold (\( p < .01 \)). This end point, as anticipated, was influenced by the presence of a \( \beta \)-blocking agent at the time of the test. Only 8% (17 patients) of the 207 patients taking \( \beta \)-blockers developed a heart rate of more than 120 beats/min, with 12% suffering a cardiac death in the first year (compared with 3% deaths in those whose rates were less than 120 beats/min). Because of the small numbers involved, this did not reach statistical significance. The development of a heart rate greater than 120 beats/min with exercise was related to cardiac mortality in the 187 patients taking digitalis at the time of the test (\( p < .001 \)), in which 13 of the 60 patients developing a heart rate greater than 120 beats/min died of cardiac causes in the first year (22%) compared with five of the remaining 127 (4%) whose heart rates never reached this threshold. In patients who were not taking digitalis, there was no difference in mortality whether or not they exceeded the heart rate threshold (3% in each group).

**Supraventricular and ventricular arrhythmias.** The presence of VEDs or couplets before, during, or after the exercise test was associated with increased cardiac mortality in the first year (table 3). The presence of supraventricular ectopic depolarizations was associated with new infarction in the first year. When patients taking \( \beta \)-blockers were analyzed separately, however, the relationship of ectopic depolarizations to cardiac mortality (and supraventricular depolarizations to new infarction) was seen only in the patients not taking \( \beta \)-blockers. There was no relationship between ectopic beats at the time of the test and cardiac mortality in those taking \( \beta \)-blockers. In patients taking digitalis at the time of the test the opposite relationship was observed. Patients taking digitalis had a higher incidence of death in the presence of VEDs (odds ratio = 3.1, \( p < .05 \)) or couplets (odds ratio = 4.3, \( p < .05 \)), but patients not taking digitalis had no such relationship. Supraventricular ectopic depolarizations were associated with new infarctions in both those taking digitalis (odds ratio = 2.3, \( p > .05 \)) and those not taking digitalis (odds ratio = 2.4, \( p < .05 \)).

**Selected clinical variables.** The relationships between selected clinical variables and cardiac mortality were explored in the group that took the exercise test. The “a priori” analysis relating these variables to the end point cardiac mortality has already been published. The following variables were found to be related to cardiac mortality in this group: New York Heart Association class greater than class I on admission (\( p > .05 \)), rales on admission (\( p > .001 \)) or pulmonary congestion on the chest x-ray in the cardiac care unit (\( p > .001 \)), and tachycardia on the qualifying electrocardiogram (\( p < .001 \)). These variables were all entered into the multivariate analysis along with exercise variables to develop the multilogistic model.

**Multiple logistic regressions.** The results of the multiple regressions on cardiac death, new myocardial infarctions and bypass surgery in the patients who performed exercise are presented in table 4. The stepwise regression of clinical and demographic variables unrelated to exercise on cardiac death within the year selected pulmonary congestion on the admission chest film and tachycardia (heart rate >90 beats/min) on the qualifying electrocardiogram as the two most important risk variables. When only exercise variables were considered, maximum developed blood pressure less than 110 mm Hg, couplets before, during, or after exercise, and the development of angina during or after exercise were selected as independent predictors of cardiac death within 1 year. The model constructed with the clinical and exercise variables selected from the stepwise regressions was significantly better (\( p < .001 \)) than the model constructed from only clinical variables. The additional information added by the exercise test variables increased the rank correlation from .604 to .689.
The stepwise logistic regressions of clinical, demographic, and exercise variables on the development of a new infarction within 1 year are shown in Table 4. Pulmonary congestion was the only clinical variable selected, while the presence of supraventricular ectopic depolarizations was the exercise variable selected.

The results of the multiple logistic regression with bypass surgery as the end point are seen in Table 4. With only clinical and demographic variables, the model selected male gender and anginal pain in the hospital before discharge. A model constructed from exercise variables alone selected ST segment depression and the development of angina during or after the stress test. Comparison of the model derived from clinical variables alone with a model constructed of the clinical and exercise variables selected from the models described above showed that the addition of exercise test variables significantly improved the correlation with bypass graft surgery (p < .01).

**Prognostic stratification.** The results of a prognostic stratification with the variables as determined above are presented in Figure 2. The blood pressure during exercise was not obtained in 12 subjects, so only 655 patients were stratified. The combination of an exercise blood pressure response greater than 110 mm Hg and absence of pulmonary congestion on the admission chest x-ray delineated a group of 454 patients that included 70% of all patients taking the exercise test and 52% of all postinfarction patients entered into the study. This group had a 1 year cardiac mortality rate of 1% compared with 13% in the other 201 patients performing the exercise test. The risk of subsequent myocardial infarction in this group was also low: 6% compared with 14% in the higher risk group (p < .01). A third stratification based on the ability to complete the low-level exercise test identified a group of 298 patients (46% of the patients taking the exercise test) with no deaths in the year after the infarction (Figure 2).

**Discussion**

How useful is the low-level exercise test as a discriminator of high and low risk? Can it, together with clinical variables, define a group at very low risk for events within the first year? We found that for all end points, the model combining exercise and clinical variables demonstrated a better relationship to cardiac death, new infarction, or bypass surgery than models composed of just clinical or exercise variables. This is somewhat at variance with the findings of Birk Madsen and Gilpin,18 who found this only in the case of new infarctions. In the 454 patients who attained a blood pressure greater than 110 mm Hg during the test and with no pulmonary congestion on the chest x-ray, the 1 year mortality rate was 1%. The low-risk group could

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**FIGURE 2.** Prognostic stratification with clinical and exercise variables. BP = blood pressure measured during the exercise test; duration < 9 min = duration of exercise test less than 9 min; duration = 9 min = completion of 9 min exercise protocol.
be further defined by the ability to complete the 9 min test to identify a postinfarction population of 298 patients with no mortality (figure 2).

The ability to take the exercise test effectively stratified patients into high- and low-risk groups. There was a 17% mortality in the 192 patients who could not take the stress test and 6% in the 667 patients who took the test (table 2). However, nearly half (38/77) of the deaths in the cardiac care unit survivors occurred in this “low risk” group.

In the group that did exercise, three features identified patients likely to suffer a cardiac death within the first year: (1) impaired exercise performance as manifested by the inability to achieve blood pressures greater than 110 mm Hg or to complete the 9 min test, (2) evidence of ischemia as delineated by development of angina during the test, and (3) electrical instability as manifest by arrhythmias during the monitoring period at rest, exercise, or recovery (table 3).

The performance of bypass surgery reflected the decisions of the many private physicians whose patients participated in this study. Evidence of ischemia (angina or ST segment depression) was strongly associated with bypass graft surgery, and it is likely that the presence of ischemia on the exercise test influenced the decision to recommend and carry out bypass graft surgery. Nineteen percent of patients with ST segment depression underwent coronary bypass surgery. If surgery influences mortality or the development of a new infarction after the initial infarction, then the incidence of surgery in the study population may distort the relationship of parameters such as ST segment depression and angina to cardiac mortality. On the other hand, the studies reported by Jennings et al.24 and Birk Madsen and Gilpin18 did not show a relationship of ST segment depression to mortality and no patients underwent bypass surgery in either of these studies.

Since we monitored only leads V_2, V_3, and aVF, the exercise electrocardiogram thus obtained would be expected to be somewhat less sensitive but more specific than 12-lead systems. The actual difference between the results from these three leads chosen to represent approximately orthogonal points and the results from a 12-lead system, however, would be expected to be small on the basis of the data of Chaitman et al.25 However, because of the patients in our and other studies who have undergone bypass graft surgery and our observation that patients exhibiting ST segment depression were more likely to undergo bypass graft surgery, it does not seem wise to draw firm conclusions about the lack of relationship of ST segment depression with exercise to cardiac mortality.

There was an increased incidence of cardiac events, cardiac death, bypass graft surgery, and new infarction in those who had arrhythmias before, during, or after the test. The stepwise regression analysis suggested that the association of the specific arrhythmias was independent of other exercise test risk factors. The association of supraventricular arrhythmias with new infarction was surprising. In analyses such as were done in this study, where a number of variables are screened to establish associations, the possibility always exists that such an association is not valid in other populations. True validation of this concept can come only by examining other populations, ideally in a prospective manner. However, the association may in fact have clinical validity, since the importance of supraventricular arrhythmias as a risk factor (for cardiac mortality) has been established in a previous study of postinfarction mortality, in which the presence of atrial fibrillation or flutter in the cardiac care unit was strongly associated with 1 year cardiac mortality.26

The role of the other stratifying tests performed as part of the multicenter stratification project,20 Holter monitoring and radionuclide-determined ejection fraction, was not evaluated in this analysis. Clearly, the addition of these expensive tests would not have improved the identification of our low-risk group. However, further stratification of the 52% of postinfarction patients at higher risk may be improved with these modalities.27

The analysis presented here indicates that exercise testing can be a very useful prognostic tool, particularly when combined with basic clinical data. Our study defines a large fraction of postinfarction patients with little likelihood of death in the ensuing year. Such individuals are unlikely to have a substantial improvement in longevity from any intervention. If our stratification scheme is validated in a prospective manner, it may have value in excluding minimally symptomatic or asymptomatic postinfarction patients from evaluation or treatment that has little likelihood of practical benefit. Reanalysis of the results of the Beta-blocker Heart Attack Trial study of the effect of propranolol after myocardial infarction suggests that benefit is confined to patients who suffered complicated infarctions, a result consistent with this philosophy of risk stratification after the infarction.28

The findings of Gibson et al.29 that predischarge exercise thallium-201 scintigraphy was a better predictor of subsequent coronary events than coronary angiography is consistent with the data presented here. In our low-risk group of 454 patients (figure 2), 53 were operated on with one subsequent death, giving a mor-
tality of 2%, similar to the mortality of 1% in the 401 patients who were not operated on. The lack of clear benefit for operating in the low-risk group, which is corroborated by the Coronary Artery Surgery Study, virtually eliminates the need to identify each and every patient with triple-vessel disease to recommend prophylactic surgery.

Summary and conclusions. Low-level exercise testing performed before discharge after myocardial infarction is safe, provides useful prognostic information, and helps identify those who are likely to undergo bypass grafting. Satisfactory performance of the exercise test in the absence of clinical factors suggesting a poor prognosis is associated with a benign course. On the basis of our results we would recommend low-level exercise testing early after infarction for all patients who are able to perform the test. Patients with satisfactory performance (elevation of blood pressure during the test to more than 110 mm Hg, completion of the test, absence of arrhythmias) and without clinical features suggesting a poor prognosis are in a very low-risk group and need not undergo invasive testing. In addition, those without angina or ST segment depression are unlikely to become bypass candidates in the ensuing year. The roles of radionuclide left ventriculography, thallium-201 scintigraphy, Holter monitoring, or coronary angiography need definition. They would seem to be of limited value in the low-risk group as we have defined it but may be of value in identifying patients with low threshold for major, ischemia-induced dysfunction among the intermediate- or high-risk groups and those who could not exercise. The value of bypass surgery or drug therapy needs validation in this low-risk group, since it is unlikely that survival can be significantly improved.

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Appendix

The Multicenter Postinfarction Research Group consisted of the following committees and hospitals:

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Mortality Committee: Frank I. Marcus (Chairman); Leonard Cobb, M.D., Jesse Edwards, M.D., and Lewis Kuller, M.D.

Biostatistical Committee: Charles L. Odoroff, Ph.D., (Chairman); Henry T. Davis, Ph.D., Joseph L. Fleiss, Ph.D., and J. Philip Miller.

Enrolling hospitals: Presbyterian Hospital in the City of New York; Roosevelt Hospital and St. Luke’s Hospital Center, New York; Highland Hospital, Rochester, NY; Jewish Hospital and St. Luke’s Hospital, St. Louis, MO; and University of Arizona Health Science Center, Tucson Medical Center, and St. Joseph’s Hospital, Tucson, AZ.

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