Long-term exercise performance after percutaneous transluminal coronary angioplasty and coronary artery bypass grafting

BERNHARD MEIER, M.D., ANDREAS R. GRUENTZIG, M.D., WALTER E. SIEGENTHALER, M.D., AND MARIA SCHLUMPF

ABSTRACT In our first 169 consecutive patients admitted to undergo percutaneous transluminal coronary angioplasty (PTCA) serial bicycle ergometric exercise sessions were scheduled to assess long-term exercise performance. In 160 of these 169 patients (95%) an average of seven ergometric measurements were available during a mean follow-up period of 29 months (range 1 to 60 months). Two groups were formed. One consisted of 132 patients in whom PTCA was successful and the other consisted of 28 patients with failure of PTCA who subsequently underwent coronary artery bypass grafting (CABG) either on an emergency basis (12 patients) or as an elective procedure (16 patients). Exercise performance was expressed as work capacity in watts according to the highest completed exercise stage. In the successful PTCA group the actual work capacities increased from 74 ± 42 W (mean ± SD) before PTCA to 122 ± 47 W at the most recent follow-up examination. In patients who underwent emergency or elective CABG the respective figures were 73 ± 34 or 65 ± 37 W before surgery and 120 ± 41 or 119 ± 41 W at the most recent follow-up examination (p < .005 for all preprocedural to postprocedural comparisons). Successful PTCA and CABG after failed PTCA improve work capacity significantly. Comparison of our results with those of surgical studies indicates that a failed attempt at PTCA before CABG does not compromise the functional outcome of the operation, regardless whether it is done on an emergency or on an elective basis. Circulation 68, No. 4, 796–802, 1983.

IN THE FIRST PATIENTS we treated with percutaneous transluminal coronary angioplasty (PTCA) serial bicycle exercise tests were done in an ongoing prospective study to determine the immediate and long-term functional outcome of the operation. Comparisons were possible between patients in whom PTCA was successful and those in whom it failed and who underwent subsequent coronary artery bypass grafting (CABG). Previous studies have shown that PTCA is able to restore coronary blood flow, alleviate symptoms, and improve left ventricular perfusion and work capacity.1–14 Other reports have addressed the topic of the use of exercise tests to determine outcome in patients who undergo CABG15–15; in some of these studies results were compared with those in a group receiving drug treatment.1–15 Their results serve as a standard for the surgically treated patients described in this report.

Patients and methods

Between September 1977 and October 1980 a total of 169 patients underwent PTCA at the University Hospital of Zurich. All of them suffered from symptomatic coronary artery disease despite adequate drug therapy with nitrates, β-blockers, and calcium antagonists. As a prerequisite, they were accepted for and agreeable to bypass surgery.

Table 1 shows the in-hospital complications, measures, and triage of these 169 consecutive patients. Nine patients (5%) were not available for follow-up exercise tests for reasons explained below. Table 2 lists some general characteristics of the remaining 160 patients constituting our study group.

Successful PTCA. Primary success according to the National Heart, Lung and Blood Institute definition (reduction of degree of diameter narrowing by ≥ 20%)16 and improvement of symptoms were achieved in 134 patients (80%). Of these 134 patients 62 (46%) remained on antianginal drug therapy. This figure subsequently increased to 58%. Recurrences occurred in 35 patients (26%) 1 to 9 months (mean 5 months) after PTCA. These were evidenced, in all cases, by angiographically measured loss of >50% of initial diameter gain and, in most cases, by conversion of stress test results from negative to positive and recurrence of previously abolished symptoms. Sixteen patients were redilated with lasting success and 16 underwent CABG.
TABLE 1
Complications, measures, and triage during initial hospitalization of 169 patients undergoing PTCA

<table>
<thead>
<tr>
<th></th>
<th>Successful PTCA (n = 134)</th>
<th>Failed PTCA (n = 35)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Death</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>MI</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Emergency CABG</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>Elective CABG</td>
<td>0</td>
<td>19</td>
</tr>
<tr>
<td>Drug therapy</td>
<td>62 (46%)</td>
<td>14 (45%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 without CABG</td>
</tr>
</tbody>
</table>

MI = myocardial infarction as evidenced by new Q waves or MB fraction of > 10% of total elevated creatine kinase.

(eight after a second and one after a third PTCA without lasting success).

No deaths occurred during hospitalization for PTCA. Four patients died during the observation period. Three of them completed at least one follow-up exercise test and their data were included in the analysis. One patient remained free of coronary symptoms and results of angiographic restudy in this patient 8 months after PTCA were normal, but he died from cancer 3 years later. The only patient whose data are not included died 2 months after PTCA of the left mainstem, which was still patent at autopsy.

Baseline and one or more follow-up exercise test results were available in 132 of the 134 patients (99%) with primary success. The most recent tests were performed 1 to 60 months (mean 28 months) after PTCA.

CABG after failure of PTCA. PTCA failed in 35 patients, 31 of whom subsequently underwent CABG either on an emergency (12 patients) or on an elective basis (19 patients). Four patients received drug treatment despite previous commitment to surgery in case of failure of PTCA. Of the 31 patients operated on, 14 (45%) remained on antianginal drug therapy. This figure subsequently increased to 57%. Recurrences defined by clinical criteria occurred in eight patients (26%) 1 to 9 months (mean 5 months) after CABG. All of them received drug treatment and did not undergo reoperation. One patient died the day after elective CABG, which was done 3 months after the failed PTCA.

Baseline and follow-up exercise tests were available in 28 of the 30 remaining patients (93%). Twelve of the 28 patients had emergency and 16 had elective CABG. The most recent tests were performed 6 to 60 months (mean 31 months) after CABG.

Protocol. Exercise tests were scheduled before and 2 days; 3, 6, 9, and 12 months; and 2, 3, and 4 years, etc., after the intervention. CABG patients had the first follow-up test 6 months and their second 12 months after the operation. Subsequent tests were performed at yearly intervals.

A total of 1059 exercise tests were performed according to a uniform protocol distributed to all participants (see below). This amounts to an average of 6.6 (range two to 12) tests for each of the 160 patients (seven tests per successful PTCA patient and five tests per CABG patient). Food and drugs were not withheld. The majority of tests were done at the University Hospital of Zurich under conditions identical to those for all routine exercise tests. The personnel supervising the tests were not aware of the study protocol or of the particular patients that were enrolled in it.

Multistage bicycle ergometric exercise in the upright position was used in all participating centers. The stationary bicycles were equipped with a variable electric or mechanical pedal resistance calibrated in watts at a constant speed maintained by the patient according to a mark on the speedometer. The bicycle seat was always adjusted for the patient's size.

The generally accepted guidelines for discontinuation of exercise, such as achievement of an age- and sex-dependent target heart rate, progressive chest pain, ST depression of ≥ 0.1 mV (new) or ≥ 0.2 mV (additional), ST elevation, complex arrhythmia, bundle branch block, blood pressure of > 220/120 mm Hg, physician's concern because of pallor, disorientation, or ataxia, and patient's request because of leg tiredness, fatigue, dyspnea, dizziness, or nausea, were observed. Table 3 depicts how often these factors led to termination of the tests in both groups and after the therapeutic intervention.

The protocol used for all exercise tests is illustrated in figure 1. Routinely stages I, II, III, IV, and V meant bicycle settings at 50, 75, 100, 125, and 150 W, respectively. However, occasional modifications of the watt selection were necessary due to inherent patient factors such as poor conditioning of the heart and technical difficulties in riding the bicycle. The scoring was based on the assumption that the work capacity should refer to a steady-state level that can be achieved in 3 to 5 min.

Therefore, the highest stage completed (i.e., 5 min for first stage and 3 min for subsequent stages) was the determination of the actual work capacity (in W) used to grade the exercise performance. This avoids basing the results on a short peak effort, which sometimes is more dependent on the patient's willpower than his circulation. To adjust for sex, age, and height, each of which

![FIGURE 1](http://circ.ahajournals.org/)

**FIGURE 1.** Test protocol for multistage bicycle ergometric exercise. Arrow indicates the point of discontinuation in an example. Since the patient did not complete the 3 min of stage III (100 W) his work capacity is assessed to be 75 W (highest completed stage).

Vol. 68, No. 4, October 1983.

*TABLE 2*  
Characteristics of 160 patients included in study

<table>
<thead>
<tr>
<th></th>
<th>Successful PTCA (n = 132)</th>
<th>Failed PTCA (CABG) (n = 28)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean age (yr)</td>
<td>50</td>
<td>49</td>
</tr>
<tr>
<td>Male (%)</td>
<td>86</td>
<td>82</td>
</tr>
<tr>
<td>SVD (%)</td>
<td>59</td>
<td>50</td>
</tr>
<tr>
<td>MVD (%)</td>
<td>41</td>
<td>50</td>
</tr>
</tbody>
</table>

SVD = single-vessel disease; MVD = multivessel disease.
TABLE 3
Assessment of and reason* for termination of stress test

<table>
<thead>
<tr>
<th></th>
<th>PTCA</th>
<th>CABG</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 132)</td>
<td>(n = 28)</td>
</tr>
<tr>
<td>Before</td>
<td>After</td>
<td>Before</td>
</tr>
<tr>
<td>(% patients)</td>
<td>(% patients)</td>
<td>(% patients)</td>
</tr>
<tr>
<td>Assessed as positive</td>
<td>97 (128)</td>
<td>34% (45)</td>
</tr>
<tr>
<td>Chest pain</td>
<td>97 (127)</td>
<td>23% (31)</td>
</tr>
<tr>
<td>Dyspnea</td>
<td>7 (9)</td>
<td>5 (6)</td>
</tr>
<tr>
<td>Fatigue</td>
<td>4 (5)</td>
<td>14 (18)</td>
</tr>
<tr>
<td>Dizziness</td>
<td>1 (1)</td>
<td>—</td>
</tr>
<tr>
<td>Leg problems</td>
<td>2 (3)</td>
<td>9 (12)</td>
</tr>
<tr>
<td>Target heart rate</td>
<td>1 (1)</td>
<td>36 (48)</td>
</tr>
<tr>
<td>ST depression</td>
<td>72 (95)</td>
<td>21 (28)</td>
</tr>
<tr>
<td>ST elevation</td>
<td>2 (3)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>1 (1)</td>
<td>—</td>
</tr>
<tr>
<td>Bundle branch block</td>
<td>1 (1)</td>
<td>1 (1)</td>
</tr>
<tr>
<td>Blood pressure</td>
<td>—</td>
<td>2 (2)</td>
</tr>
</tbody>
</table>

Values in parentheses are n values.
Before = test before first therapeutic intervention; after = last available test or test before repeat intervention.

*Several reasons may have applied simultaneously.

*p < .05.

may influence the performance on a bicycle, the actual work capacity can be expressed as percentage of an individually preset target work capacity, as described elsewhere.1

For statistical comparisons the Student’s t test and the corrected chi-square test were used when appropriate. A p < .05 was considered significant.

Results

Positive stress test results before the intervention were found in 97% of patients in whom PTCA was successful and in 96% of patients in whom it failed and who underwent subsequent CABG (table 3). At the most recent follow-up examination results were positive in 34% and 36%, respectively. Initially, chest pain and ST shifts largely constituted the reasons for termination of the stress tests (table 3). Successful PTCA reduced the incidence of chest pain during exercise testing from 97% to 23% and the incidence of ST depression from 72% to 21% from the time of the first to the time of the last test (which was the test performed at the time of recurrence, if an additional intervention was required). The respective figures for CABG were 89% to 29% for chest pain and 82% to

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**TABLE 4**

Exercise performance (in W) of patients undergoing PTCA or CABG

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
<th>Follow-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Successful PTCA</td>
<td>74±42</td>
<td>113±38</td>
<td>122±47</td>
</tr>
<tr>
<td>(n = 132)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABG emergency</td>
<td>73±34</td>
<td>120±41</td>
<td></td>
</tr>
<tr>
<td>(n = 12)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CABG elective</td>
<td>65±37</td>
<td>119±41</td>
<td></td>
</tr>
<tr>
<td>(n = 16)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are mean ± SD.

Before = test before therapeutic intervention; after = test immediately after PTCA; follow-up = last available test or test before repeat intervention.

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**FIGURE 2.** Exercise performance expressed as mean actual work capacity in percent of expected work capacity. There is similar improvement with all therapy modalities. Before and after = within days of procedure; follow-up = 1 to 60 months (mean 23 months) after procedure; Em = emergency; el = elective.
14% for ST depression. Inversely, the number of patients achieving their age- and sex-adjusted target heart rates increased from 1% to 36% after PTCA and from 4% to 32% after CABG. There was also an approximately fourfold increase in fatigue as reason for termination of the test after both PTCA and CABG.

Table 4 and figure 2 show that exercise performance expressed by the actual watt value or by the percentage of an age-, sex-, and height-adjusted target value significantly improved as a result of surgical intervention both in patients in whom PTCA was successful and in patients who underwent CABG (emergency or elective) after failure of PTCA. Figure 3 indicates that exercise performance of patients in whom PTCA was successful was additionally improved during the first year after the intervention and remained stable after-ward. Exercise performance of patients who underwent CABG remained unchanged at a level significantly lower than that in PTCA patients. For these statistics, tests indicating a recurrence were used as the latest follow-up test if the recurrence prompted the use of another invasive procedure. Results from drug-treated patients with recurrences (three in PTCA group and eight in CABG group), however, were continuously included.

Figure 4 illustrates data from patients with continued success after PTCA, from those with a recurrence treated medically, and from those with a recurrence treated with an additional invasive procedure, be it repeat PTCA, CABG, or both. The trough during the first year in the group of patients who underwent a second procedure illustrates the recurrence rate (drop

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**FIGURE 3.** Long-term exercise performance expressed as actual work capacity in watts (mean ± SD) in patients undergoing PTCA and CABG. The results after PTCA improved further during the first year and were significantly better than those after CABG at 2 and 3 years. N = number of patients.

**FIGURE 4.** Long-term exercise performance expressed as mean actual work capacity in patients in whom PTCA was successful. All recurrences and further procedures took place within the first 2 years. N = number of patients; CS = continued success; R = recurrence treated with drugs; R + FP = recurrence and further procedure (16 repeat PTCA, nine repeat PTCA and CABG, seven CABG).
to pre-PTCA exercise tolerance) and the benefit of the second interventional procedure.

Figure 5 illustrates data from patients with continued success after CABG and from those with recurrence after CABG, all of whom were receiving drug treatment.

Figure 6 shows the exercise performance of patients with single-vessel disease compared with that of patients with multivessel disease. The results are given separately for the PTCA and CABG groups. Patients with single-vessel disease showed slightly more improvement and better results than patients with multivessel disease after both PTCA and CABG. The differences, however, were not statistically significant.

**Discussion**

Survival in coronary artery disease seems to be directly correlated to performance during exercise testing. Hence, determinations of work capacity as a measure of performance provide valuable information, not only about success of procedures like PTCA and CABG, but also about life expectancy of patients undergoing them. These determinations are not affected by the well-known uncertainties associated with the

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**FIGURE 5.** Long-term exercise performance expressed as mean actual work capacity in patients with CABG. No repeat interventions were done. N = number of patients; CS = continued success; R = recurrence.

**FIGURE 6.** Exercise performance expressed as actual work capacity in watts. Patients with single-vessel disease had higher mean values after both treatment modalities than those with multivessel disease, but the differences were not significant. Values are mean ± SD. SVD = single-vessel disease; MVD = multivessel disease; before and after = within days of procedure; follow-up = 1 to 60 months (mean 23 months) after procedure; NS = not significant.
diagnosis of coronary artery disease on the basis of exercise test results\textsuperscript{26, 27} since the diagnosis is already established and is not the issue.

The exercise test schedule should include a preoperative test if at all possible. Repetitions early after PTCA and 3, 6, 12, 24, 36, etc., months after both PTCA and CABG seem appropriate, if complemented by additional tests whenever symptoms change.

Bicycle ergometry was used in this study to assess exercise performance. Its advantages over treadmill tests are greater stress on the cardiovascular system\textsuperscript{28} and an easy and quite accurate readout of the actual amount of work performed. If desirable, inherent patient variables can be eliminated by indicating the actual work performed as a percentage of a target work capacity adjusted for age, sex, and height of the patient. This was not of great importance in this study, since the compared groups were matched (table 2) and since intrapatient changes were of main interest.

Antianginal drugs were not withheld before the exercise tests and may have blurred, but certainly not boosted, the beneficial effect of the interventions. According to the selection criteria all patients were initially on adequate combination therapy. After successful PTCA 46% and after CABG 45% of the patients remained on antianginal therapy (table 1), usually on reduced doses. The reason for continuing the drug therapy was not uniform but was predominantly of a preventive nature. On the occasion of the most recent stress test, the percentages of patients on antianginal therapy were 58% for PTCA and 57% for CABG.

Other authors have reported continuation of drug therapy after CABG in 25% to 65% of their patients.\textsuperscript{9, 10, 12, 14, 15}

Positive stress test results were obtained in 97% of all patients before the interventions and in only 35% of the most recent follow-up examinations, which includes the examination at the time of recurrence in the 43 patients (27%) in whom there was no lasting success. There was a shift from chest pain and electrocardiographic changes to target heart rate and fatigue as the reasons for termination of the stress test after both PTCA and CABG (table 3); this alone would document the beneficial effects of the procedures.

Exercise performance significantly and durably improved after all the interventions (PTCA, emergency CABG, or elective CABG), as depicted in table 4, with no apparent difference between patients who underwent emergency and elective surgery (figure 2).

In PTCA patients there was an additional improvement during the first year after the intervention (figure 3). Further improvement at the site of PTCA, known from angiographic studies to occur during the first months after the procedure,\textsuperscript{1} is more likely to be responsible for this than the gradual exclusion of patients with recurrences. As shown in figure 4, deletion of data indicating recurrences does not affect this improvement trend.

The frequent repetition of stress tests, resulting in improved technique and in stimulation of patients to gain and maintain physical fitness, may also have contributed to the improvement during the first year. However, this training effect should be common to all groups. In the group of patients who were treated with drugs and suffered recurrences (three patients with recurrence by angiographic criteria without symptoms), there was improvement during the first year. This improvement was even pronounced due to an outstanding performance (175 W) of one of the three patients at 1 year. The surgical group, however, showed only a minimal increment in work capacity between the test at 6 months and the test at 1 year. This indicates that the training effect was not a major factor in the postinterventional improvement observed in the PTCA group.

At 2 and 3 years the actual work capacity of patients needing surgery after failure of PTCA was significantly inferior to that of patients who underwent PTCA alone. At 4 years the numbers were too small for a valid comparison. Excluding data from patients who had evidence of recurrence but underwent no further procedure (three in PTCA group, eight in CABG group) diminishes the difference between PTCA and CABG patients to below the significance level (figures 4 and 5). Obviously, the threshold indicating the need to perform repeat operation was higher after CABG than after PTCA. Thus, recurrent symptoms reducing exercise tolerance were invasively treated in patients after PTCA, but not in patients after CABG, which compromised the mean outcome in the CABG group and was partially responsible for their less favorable long-term outcome. The stable course in both groups after the first year (figure 3) at a level significantly higher than before the intervention reflects that there is indeed a lasting benefit from both procedures.

The surgical results presented here compare favorably to previous reports of patients undergoing surgery without preceding attempt of PTCA; Nitter-Hauge\textsuperscript{5} reported an improvement in the work capacity of patients after CABG of up to 60% of that of age-matched normal subjects. Sivertssen et al.\textsuperscript{6} found a 65% increase in work capacity after CABG. As for the comparison between surgical and drug treatment, several studies have shown improved exercise tolerance in both surgically and drug-treated patients, but the improvement
was always significantly greater in the surgical groups. In three studies exercise tolerance was found to be improved in the surgical groups, but not in the drug-treated control groups.

The recurrence rate of symptoms of 26% (8/31 patients) over more than 2 years in our surgical group is in keeping with the occlusion rate in single vein grafts of 20% reported from the Cleveland Clinic or the 40% attrition rate of at least one bypass graft reported by the Veterans Administration Cooperative Study for the time span of approximately 1 year. (For comparison, the recurrence rate of our patients with successful PTCA was also 26%.)

It is of note that in both the group in which PTCA was successful and in the CABG group recurrences only occurred within the first 9 months (mean 5 months) after the procedure.

Patients with single-vessel disease showed better exercise performance than those with multivessel disease after both PTCA and CABG (figure 6). However, the differences were not statistically significant.

We conclude that successful PTCA and CABG practically normalize exercise capacity, as assessed by bicycle ergometry. They also achieve durably negative test results in approximately two-thirds of the patients. Results are slightly better after PTCA than after CABG done for failed PTCA. Failure of PTCA preceding CABG does not seem to compromise the functional result of the surgery, regardless whether it is performed on an emergency basis immediately after the PTCA attempt or electively.

References

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