Exercise Electrocardiography and Myocardial Scintigraphy in the Serial Evaluation of the Results of Percutaneous Transluminal Coronary Angioplasty

JEAN-MARIE SCHOLL, M.D., BERNARD R. CHAITMAN, M.D., PAUL ROBERT DAVID, M.D., GEORGES DUPRAS, M.D., GENEVIÈVE BRÉvers, M.D., PERE GUiteras Val, M.D., JACQUES CRÉPEAU, M.D., JACQUES LESPÉRANCE, M.D., AND MARTIAL G. BOURASSA, M.D.

SUMMARY The diagnostic value of exercise electrocardiography using 14 leads and thallium-201 scintigraphy were evaluated in 54 of 70 patients who underwent percutaneous transluminal coronary angioplasty (PTCA), both in the initial assessment and serial follow-up of patients after PTCA. Of the 45 patients who had successful PTCA, 36 had complete noninvasive studies performed before and 1 month after PTCA. Thirty-three of these 36 were asymptomatic 1 month after PTCA; the number of patients with an abnormal exercise ECG decreased from 20 to seven (p < 0.01) and with an abnormal thallium-201 scintigram from 21 to six (p < 0.001); the number of patients who had at least one of the two tests positive decreased from 26 to 10. The average treadmill time increased from 448 ± 183 to 618 ± 119 seconds (p < 0.001), and the average rate-pressure product increased from 19.81 ± 6.4 to 31.35 ± 4.6 units × 10⁶ (p < 0.001). Of the 10 patients with a positive test, two had a partial restenosis ≥ 50% but < 70% on the 6-month control angiogram; two had a residual stenosis ≥ 50% in a vessel that was not dilated and three had an abnormal scintigram before and 1 month after PTCA that subsequently became negative at 6 months. Six months after PTCA, a control angiogram was performed in 20 asymptomatic patients; 18 had an excellent PTCA result and two had a partial restenosis ≥ 50% but < 70%. The stress test results were normal in patients with a successful 6-month PTCA and abnormal in the two patients with a partial restenosis.

Ten patients redeveloped angina within 3 months of PTCA; nine developed a restenosis ≥ 60% and one had a 90% left circumflex stenosis that could not be dilated or grafted. Six of the 10 patients had a normal exercise ECG and scintigram at 1 month that became abnormal when symptoms recurred. The rate-pressure product before PTCA and when angina symptoms recurred was similar (18.00 ± 2.20 vs 23.58 ± 6.7 units × 10⁶) (NS).

In conclusion, the use of clinical symptoms in conjunction with the physiologic data, ECG and myocardial scintigraphy acquired during exercise provide important short-term data on the angiographic evolution of PTCA results. The noninvasive tests may be useful in determining guidelines for repeat angiography in patients who have had PTCA.

PERCUTANEOUS transluminal coronary angioplasty (PTCA) is a new technique that may be useful in the treatment of 5–10% of patients with coronary artery disease who are suitable candidates for coronary artery bypass grafting.¹ ¹³ However, the method is still considered an investigational procedure and many issues are not resolved.⁴ ⁵ Most reported series of PTCA are small and follow-up is short because the technique requires considerable expertise, is relatively new, and suitable patient recruitment is limited in most hemodynamic laboratories.⁶-¹⁴ The role of noninvasive diagnostic tests in the selection and serial follow-up of patients who are considered for PTCA is not well defined. In some reports, stress test results and radionuclide studies are not discussed, and in others the sequential results of both tests are not described.¹⁵ ¹⁸ The aim of this study is to evaluate exercise electrocardiography using 14 leads in conjunction with thallium-201 scintigraphy in a patient population referred for PTCA and to assess the diagnostic value of both in the serial follow-up of patients after PTCA.

Methods

Patient Population

Between March 1980 and February 1981, 70 patients underwent a PTCA procedure at our hospital. Noninvasive tests were not performed in 14 patients because of unstable angina; two patients were excluded because the exercise ECG and thallium scintigrams were technically inadequate for study. The 54 remaining patients (42 men and 12 women) had a maximal stress test performed with rest and exercise thallium myocardial scintigraphy; the average age was 49 years (range 30–71 years). The baseline rest ECG was abnormal in 12 patients: three had a transmural myocardial infarction by Minnesota Code criteria and nine had ST-T-wave abnormalities.¹⁹ ²⁰ In 31 patients, β blockers could not be progressively stopped before PTCA because of increased anginal symptoms (16 patients) or physician refusal (15 patients). None of the patients were taking digitalis in the 3-week interval before the tests or nitrates the day of the test. After PTCA, all tests were performed without medication. In asymptomatic patients, exercise was continued to at least 85% of the maximum age-predicted heart rate or 2 mm or more of horizontal or downsloping ST-segment depression.²⁰ In patients who re-
developed angina symptoms, the standard exercise end points were used.21,22

Patient premedication was given before PTCA after the noninvasive tests were performed and consisted of sulfinpyrazone, 200 mg four times daily for 2 days, and diltiazem, 120 mg at bedtime and the morning of the procedure. During PTCA, an i.v. perfusion of nitroglycerin was maintained with supplementary boluses of intracoronary nitroglycerin when needed. Heparin, 10,000 units i.v., and rheomacrodex, 200 ml i.v., were administered at the onset of the procedure. All patients received sulfinpyrazone, 200 mg four times daily, for 6 months after PTCA. Beta blockers were progressively decreased and stopped in the 7–10 days after PTCA.

The exercise test was repeated at 1, 3 and 6 months after successful PTCA with thallium-201 scintigrams at 1 and 6 months. A control angiogram was routinely performed 6 months after PTCA in asymptomatic patients. The noninvasive tests were performed within 1 week of coronary angiography. In the patients who became symptomatic after the initially successful PTCA, coronary angiography and the sequence of noninvasive tests were repeated after 6 months (fig. 1).

Exercise Stress Test

The exercise stress tests were performed following the Bruce protocol modified by a preliminary warmup at 1.7 mph and a 5% grade.23 Cuff blood pressure measurements were obtained each minute throughout the test. The ECG was monitored continuously and recorded each minute during and for 3 minutes after exercise. All patients were in a fasting state and had not smoked for at least 2 hours before the test. In the 54 patients who had a stress test before PTCA, exercise was continued until exhaustion or severe dyspnea in 23 patients, progressive angina in 28 patients and a decrease in systolic blood pressure during progressive exercise in three patients. Fifteen ECG leads, which included the standard 12 leads and bipolar leads CC, CM, and ML, were recorded as previously described.21,22,24–26 The exercise ECG was considered abnormal if three consecutive complexes met any one of the following criteria: (1) horizontal or downsloping ST-segment depression ≥ 1 mm for 0.08 second after the J point; (2) a slow upsloping ST-segment depressed ≥ 2 mm at 0.08 second after the J point; or (3) ST segment-elevation ≥ 1 mm for 0.06 second. In the patients who had ST-segment depression at rest, an additional ST-segment shift of 1 mm was required to classify the test as abnormal.

Myocardial Scintigraphy

Thallium scintigrams were acquired using standard techniques.27 One minute before exercise was terminated, 1.5–2.0 mCi of thallium-201 was injected i.v. and 5–10 minutes later, imaging was performed in the anterior, 30° and 60° left anterior oblique views using an Ohio nuclear series 550 mobile scintillation camera with a high-resolution, parallel-hole collimator. Images contained 300,000 counts over the heart using a 20% window and were stored on magnetic disc in a 128 × 128 matrix (V.I.P. 550). The images were processed in digital format with 11% background subtraction. Both the processed and analog images were photographed in black and white on 8 × 10-inch film.

**FIGURE 1.** Patients who had noninvasive tests (NIVT) before and after percutaneous transluminal coronary angioplasty (PTCA).
Reperfusion images in the same views were obtained 4 hours later under the same conditions. In the three patients with an abnormal reperfusion scan, rest images were obtained 5–7 days later.

Matching views from exercise and reperfusion studies were displayed as pairs and interpreted by three observers without knowledge of the clinical, angiographic or electrocardiographic findings. Each image was divided into five approximately equal segments, for a total of 15 segments, using the technique described by Rigo and colleagues. The thallium uptake of each segment was classified normal (0), mildly reduced (1) or severely reduced (2) by a consensus of observers. A scintigraphic score was obtained by summing the three views during exercise and reperfusion. In the patients with an abnormal reperfusion score, the difference between the exercise-reperfusion scintigrams determined the total scintigraphic score.

Cardiac Catheterization

Selective right and left coronary angiography was performed by the percutaneous technique using precoated polyethylene catheters as previously described. Each vessel was filmed in multiple views, including craniocaudal and caudocranial sagittal angulation views. Transluminal coronary angioplasty was performed using the technique described by Gruntzig. Coronary stenoses were expressed as the percent luminal narrowing compared with the nearest normal arterial segment in the view that appeared the most severe. The angiograms were reviewed by the same three angiographers simultaneously before and after PTCA. An increase in 20% of the luminal diameter or a decrease of 50% in the mean transstenotic arterial pressure gradient determined a successful result. Of the 54 patients who had a PTCA attempt performed and who had noninvasive tests before PTCA 45 had one, seven had two- and two had three-vessel disease; 41 patients had LAD stenosis. Intercoronary collateral vascularization was present in four patients before PTCA and was not visible immediately after the procedure. The left ventricular contraction pattern evaluated in the 30° right anterior oblique position was normal in 46 patients.

Analysis of Results

The 36 patients who had a maximal stress test and scintigraphy before and after PTCA were compared. Nonparametric differences were examined using a chi-square test. Parametric differences were examined using the t test and analysis of variance.

Results

PTCA was successful in 47 arteries of 45 patients. The average luminal narrowing decreased from 78 ± 13% to 35 ± 12% (p < 0.001) and the transstenotic gradient from 46 ± 17 mm Hg to 12 ± 8 mm Hg (p < 0.001). The maximum luminal narrowing observed immediately after successful PTCA was ≤ 50% in 42 patients and 51–70% in three patients.

Three of the 45 patients had prolonged chest pain during the PTCA procedure and had a slight increase in the CK-MB isoenzyme (36, 26 and 20 IU/l, respectively). The ECG after PTCA was similar to baseline in all patients.

Before PTCA

Fifty-four patients underwent a maximal stress test using 14 ECG leads and had a myocardial scintigram during exercise. The exercise ECG was abnormal in 32 of the patients (59%) and the thallium-201 scintigram in 36 (67%). Seven of the 10 patients who had both a negative exercise ECG and normal scintigram failed to achieve at least 85% of the maximum age-predicted heart rate. The test was stopped in five patients because of fatigue, in one patient because of angina pectoris and in another because of an exercise-induced 20-mm Hg drop in systolic blood pressure. When the seven patients with a submaximal test were excluded, the sensitivity of the exercise ECG was 78%, the exercise scintigram was 80% and one or both of the tests were abnormal in 94% (44 of 47) of the patients.

The average depth of ST-segment depression was 2.0 ± 1.1 mm (± SD) in the 32 patients with an abnormal ECG and the average number of positive ECG leads was 4.5 ± 2.4 per patient. Three patients had ST-segment elevation ≥ 1 mm. The average treadmill time was 444 ± 180 seconds; 23 patients could not complete Bruce stage 1. The average rate-pressure product at peak exercise was 20.83 ± 5.8 units × 10⁵. The physiologic data were similar in patients with normal and abnormal exercise ECGs.

The average exercise myocardial scintigraphic score was 6 ± 4; 20 patients had a score of 6 or greater. In the 36 patients who had an abnormal scan, the perfusion defect invariably occurred in the left ventricular segment supplied by the stenotic artery. Five of the nine patients who had multivessel disease had perfusion defects in at least two noncontiguous ventricular segments.

After PTCA

Of the 45 patients who had a successful PTCA, 36 underwent complete noninvasive studies before and 1 month after PTCA. Twenty of the 36 who remained asymptomatic had repeat noninvasive tests and coronary angiography at 6 months. In one patient, a silent transmural myocardial infarction was detected 3 months after PTCA. Angina pectoris recurred in three patients in the month after PTCA and in seven additional patients within 3 months of PTCA (fig. 1).

Asymptomatic Patients

One Month After PTCA

Thirty-three patients were asymptomatic 1 month after PTCA. The number of patients with an abnormal exercise ECG decreased from 20 before PTCA to seven after (p < 0.01) and with an abnormal thallium-201 scintigram from 21 before to six after (p < 0.001). The number of patients who had at least one of the tests positive decreased from 26 to 10 (p < 0.01) (table 1). The average treadmill time increased from
448 ± 183 to 618 ± 119 seconds (p < 0.001) (fig. 2) and the average rate-pressure product increased from 19.81 ± 6.4 to 31.35 ± 4.6 units × 10^3 (p < 0.001). The increases in treadmill time and rate-pressure product after PTCA were significant for the patients who were taking β blockers before PTCA and for the patients who were not.

Among the seven asymptomatic patients who had an abnormal exercise ECG, one (patient 15) had an 80% stenosis dilated to 30% that partly restenosed to 60% at control angiography performed 6 months after PTCA (fig. 3) and two (patients 49 and 56) had a residual stenosis ≥ 50% in a vessel that was not dilated. When the noninvasive test results obtained before and after PTCA were compared, the exercise ECG was abnormal at a similar rate-pressure product in two patients and became abnormal at a higher rate-pressure product in another patient. Among these three patients, the scintigraphic score before and after PTCA was almost identical in two patients; the third patient did not have a perfusion defect before or after PTCA.

Two patients (nos. 20 and 55) had a negative exercise ECG before PTCA but a positive test 1 month after PTCA. Both had an excellent PTCA result at the 6-month control angiogram. When the noninvasive test results obtained before and after PTCA were compared, the treadmill time increased by 100% and 158% and the rate-pressure product by 94% and 249%, respectively. The maximum depth of ST-segment depression was 2 mm of horizontal and 3.2 mm of upsloping ST-segment depression at 0.08 second after the J point; both ECGs rapidly normalized in the recovery period. The remaining two patients have not yet had a control angiogram.

Of the six asymptomatic patients who had persistent abnormal thallium scintigrams after PTCA, two (patients 15 and 27) had a partial restenosis ≥ 50% but < 70% at 6 months. Patient 49 had a residual stenosis ≥ 50% in a vessel that was not dilated. Patients 1, 20 and 24 had an abnormal scintigram before and 1 month

![Figure 2](image-url)  
**Figure 2.** Treadmill work time before and after percutaneous transluminal coronary angioplasty (PTCA) in patients who were symptom-free (top) and in those who redeveloped anginal symptoms (bottom).
after PTCA that became negative at 6 months even though treadmill time and rate-pressure product were similar or greater at 6 months (fig. 4).

Three Months After PTCA

Twenty-six patients remained asymptomatic 3 months after PTCA. Five of the six who had an abnormal exercise ECG at 1 month remained abnormal at 3 months. The maximum depth of ST-segment depression and number of positive ECG leads were similar in both tests, as were the rate-pressure product and treadmill work time. Two patients (nos. 27 and 70) had a normal exercise ECG at 1 month but developed an abnormal exercise ECG at 3 months at a higher rate-pressure product. The thallium scintigram was abnormal at 1 month in patient 27 and normal in patient 70. The remaining 19 patients had a normal exercise ECG. The average treadmill time at 1 and 3 months was similar among patients with an abnormal (573 ± 88 vs 559 ± 127 seconds) and a normal (630 ± 117 vs 632 ± 130 seconds) exercise ECG. The average rate-pressure product was also similar.

Six Months After PTCA

A control angiogram was performed in 20 asymptomatic patients; 18 have had an excellent PTCA result, two of whom have residual coronary disease. Two patients have a partial restenosis ≥ 50% but < 70%. Progression of coronary disease in nondilated arteries was not observed in the 6 months since PTCA. The left ventricular contraction pattern was unchanged compared with left ventriculogram before PTCA in the 20 patients. The two patients who had an increase in CK-MB after PTCA and who underwent noninvasive tests were asymptomatic at 6 months, and coronary angiography showed that PTCA had been successful. One patient had normal exercise ECG and thallium studies at 1 and 6 months. Another (patient 55, table 1)

### TABLE 1. Clinical, Angiographic and Noninvasive Tests in the 11 Asymptomatic Patients Who Initially Had Successful Percutaneous Transluminal Coronary Angioplasty but Had a Persistent or Developed an Abnormal Test Afterwards

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Artery</th>
<th>Mean transstenotic gradient (mm Hg) Before/After</th>
<th>Exercise myocardial scintigraphic score Before/1 mo./6 mo.</th>
<th>Treadmill time (sec) Before/1 mo./3 mo./6 mo.</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>63</td>
<td>F</td>
<td>LAD</td>
<td>80/30/60 (50/5)</td>
<td>4/4/2</td>
<td>180/450/420/450</td>
</tr>
<tr>
<td>27</td>
<td>54</td>
<td>M</td>
<td>LAD</td>
<td>80/25/50 (60/5)</td>
<td>3/3/3</td>
<td>540/635/510/540</td>
</tr>
<tr>
<td>45</td>
<td>61</td>
<td>M</td>
<td>LAD</td>
<td>85/40/— (50/12)</td>
<td>0/0/0</td>
<td>540/540/465/540</td>
</tr>
<tr>
<td>66</td>
<td>47</td>
<td>F</td>
<td>LAD</td>
<td>60/30/— (50/15)</td>
<td>0/0/—</td>
<td>490/480/480/—</td>
</tr>
<tr>
<td>70</td>
<td>53</td>
<td>M</td>
<td>LAD</td>
<td>80/50/—</td>
<td>0/0/—</td>
<td>620/660/600/—</td>
</tr>
<tr>
<td>49*</td>
<td>54</td>
<td>M</td>
<td>RCA</td>
<td>85/50/50 (4/4/—)</td>
<td>600/600/1/—</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>34</td>
<td>M</td>
<td>LAD</td>
<td>80/30/30 (70/28)</td>
<td>5/5/0</td>
<td>660/675/780/720</td>
</tr>
</tbody>
</table>

Successful PTCA

1 | 36 | M | LAD | 85/35/20 (80/28) | 3/3/0 | 810/780/600/660 |
2 | 51 | F | LAD | 80/25/25 (40/8) | 2/3/0 | 240/480/540/520 |
3 | 61 | M | LAD | 90/30/30 (45/10) | 6/4/0 | 300/600/585/585 |
4 | 52 | M | LAD | 95/20/20 (40/10) | 15/0/0 | 240/620/660/660 |

*Also appears in table 2 because angina symptoms reappeared between 1 and 3 months.

Abbreviations: PTCA = percutaneous transluminal coronary angioplasty; LAD = left anterior descending coronary artery; RCA = right coronary artery; LCx = left circumflex coronary artery.

![Figure 4. An isolated 80% stenosis of the left anterior descending coronary artery (LAD) was dilated to 25% in this 51-year-old woman (patient 20) who was in angina class III before and was asymptomatic after percutaneous transluminal coronary angioplasty (PTCA) (table 1). The exercise ECG was abnormal before and at 1 and 6 months after PTCA. The scintigram was abnormal before and 1 month after PTCA but became normal 6 months later. The 6-month control and angiogram revealed the same 25% stenosis in the LAD. AP = anteroposterior; HR = heart rate.](http://circ.ahajournals.org/doi/abs/10.1161/01.CIR.66.2.384)
had an abnormal exercise ECG at 1, 3 and 6 months at a higher rate-pressure product and treadmill work time. The exercise thallium scan was normal.

In the remaining 17 patients, the exercise ECG results were similar to the results at 3 months; average treadmill time was also similar (fig. 2). The scintigraphic results were normal in all 18 patients with a successful 6-month PTCA and abnormal in the two patients (nos. 15 and 27) with a partial restenosis (table 1).

**Symptomatic Patients**

Ten patients redeveloped angina symptoms an average of 6 weeks (range 2–14 weeks) after PTCA (table 2). Three (patients 4, 50 and 59) were symptomatic within 1 month of PTCA and seven others within 3 months of PTCA. Seven patients had an abnormal exercise ECG before PTCA and eight when symptoms reappeared after PTCA; eight patients had an abnormal thallium scintigram before PTCA and seven when symptoms reappeared. The average treadmill time before and when symptoms reappeared after PTCA was similar (380 ± 147 vs 410 ± 175 seconds) (fig. 2), as was rate-pressure product (18.00 ± 2.2 vs 23.58 ± 6.7 units × 10³).

In patient 49, the thallium scan was almost identical before and at 1 and 3 months after PTCA, but symptoms reappeared only at 3 months. The exercise ECG was abnormal 1 month after PTCA. Coronary angiography revealed a successful dilation but the persistence of a 90% left circumflex stenosis in which a dilation could not be performed and the distal vessel was not suitable for aortocoronary bypass grafting. In the six patients who were asymptomatic at 1 month but became symptomatic between 1 and 3 months (patients 6, 12, 30, 32, 42 and 68), the exercise ECG and thallium scintigrams were normal at 1 month, but one or both of the tests became abnormal when symptoms reappeared. The treadmill work time in the six patients increased from 340 ± 155 seconds before PTCA to 633 ± 167 seconds one month after PTCA (p < 0.02), but then decreased to 453 ± 198 seconds at the time that angina symptoms reappeared (p < 0.10) (table 2). The rate-pressure product increased from 17.09 ± 2.24 to 33.7 ± 2.81 units × 10³ (p < 0.001), but then decreased to 24.04 ± 7.46 units × 10³ when angina reappeared (p < 0.05).

The left ventricular contraction pattern was unchanged from that on the left ventriculogram before PTCA except in patient 32, who had a silent infarct 3 months after PTCA and the new appearance of segmental akinesis. The exercise ECG and scintigram normalized 1 month after successful PTCA in this patient but became abnormal after infarction (table 2).

In seven of the 10 patients who developed a restenosis, a second PTCA was attempted. Among the six patients who had a successful second PTCA, all were asymptomatic an average of 5 months later; all had a normal exercise ECG and thallium scintigrams at 1 month (fig. 5). The exercise ECG became abnormal at 3 months and 6 months, respectively, in two patients (nos. 12 and 30) who underwent 6-month control angiography. Both had a normal myocardial scintigram but had restenosed to 60%; two other patients who had a control angiogram at 6 months and a normal exercise ECG and myocardial scintigram had a successful second PTCA.

**Discussion**

Exercise electrocardiography and radionuclide studies provide valuable objective data in the initial assessment and serial follow-up of patients with coronary artery disease. Percutaneous transluminal coronary angioplasty is a new therapeutic advance that directly affects the angiographic evolution of patients with ob-

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**TABLE 1.** (Continued)

<table>
<thead>
<tr>
<th>Rate-pressure product (10³ units) Before/1 mo./3 mo./6 mo.</th>
<th>Maximum depth of ST-segment shift (mm) Before/1 mo./3 mo./6 mo.</th>
<th>Number of positive ECG leads Before/1 mo./3 mo./6 mo.</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.08/32.54/31.68/33.30</td>
<td>3/2/2/2</td>
<td>10/5/4/4</td>
</tr>
<tr>
<td>17.7/23.40/32.67/23.04</td>
<td>0/0/1/0</td>
<td>0/0/4/0</td>
</tr>
<tr>
<td>28.31/29.40/29.20/27.07</td>
<td>2.5/2/3/1.5</td>
<td>5/3/5/5</td>
</tr>
<tr>
<td>27.06/29.99/30.97/---</td>
<td>3/3/3/--</td>
<td>9/9/9/--</td>
</tr>
<tr>
<td>29.70/31.28/35.02/---</td>
<td>2/0/2/--</td>
<td>5/0/6/--</td>
</tr>
<tr>
<td>20.57/36.54/---/---</td>
<td>0/2.5/--/--</td>
<td>0/4/--/--</td>
</tr>
<tr>
<td>37.59/38.01/40.26/37.93</td>
<td>5/3/3/3</td>
<td>6/7/7/5</td>
</tr>
<tr>
<td>20.16/34.10/27.36/31.36</td>
<td>0/0/0/0</td>
<td>0/0/0/0</td>
</tr>
<tr>
<td>18.14/35.28/40.80/38.41</td>
<td>0/2/0/1</td>
<td>0/5/0/5</td>
</tr>
<tr>
<td>15.52/33.00/39.12/37.70</td>
<td>1/0/0/0</td>
<td>4/0/0/0</td>
</tr>
<tr>
<td>7.79/27.80/49.95/32.02</td>
<td>0/3.2/3/2</td>
<td>0/4/4/2</td>
</tr>
</tbody>
</table>

90% LCx stenosis not attempted

50% 1st diagonal branch not attempted
Table 2. Clinical, Angiographic and Noninvasive Test Results in the 10 Patients Who Had an Initially Successful Percutaneous Transluminal Coronary Angioplasty and Subsequently Became Symptomatic

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Symptomatic</th>
<th>Angiographic results</th>
<th>Transstenotic gradient</th>
<th>Exercise myocardial scintigraphic score</th>
<th>Treadmill time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>1 month</td>
<td>(% luminal narrowing)</td>
<td>(mm Hg) Before/after</td>
<td>Before/1 mo.</td>
<td>Before/1 mo.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td>When symptoms reappeared</td>
<td>48/25</td>
</tr>
<tr>
<td>4</td>
<td>51</td>
<td>F</td>
<td>RCA</td>
<td>95%</td>
<td>70%</td>
<td>95%</td>
<td>48/25</td>
</tr>
<tr>
<td>50</td>
<td>41</td>
<td>M</td>
<td>LAD</td>
<td>50%</td>
<td>30%</td>
<td>75%</td>
<td>24/10</td>
</tr>
<tr>
<td>59</td>
<td>55</td>
<td>M</td>
<td>LAD</td>
<td>65%</td>
<td>20%</td>
<td>65%</td>
<td>45/5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RCA</td>
<td>65%</td>
<td>20%</td>
<td>65%</td>
<td>45/5</td>
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<table>
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<th></th>
<th></th>
<th>1–3 months</th>
<th>Angiographic results</th>
<th>Transstenotic gradient</th>
<th>Exercise myocardial scintigraphic score</th>
<th>Treadmill time (sec)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Before</td>
<td>After</td>
<td>When symptoms reappeared</td>
<td>Before/1 mo.</td>
</tr>
<tr>
<td>49</td>
<td>54</td>
<td>M</td>
<td>RCA</td>
<td>85%</td>
<td>50%</td>
<td>50%</td>
<td>44/24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cx</td>
<td>90%</td>
<td>90%</td>
<td>90%</td>
<td>44/24</td>
</tr>
<tr>
<td>6</td>
<td>48</td>
<td>F</td>
<td>RCA</td>
<td>70%</td>
<td>40%</td>
<td>70%</td>
<td>53/23</td>
</tr>
<tr>
<td>12</td>
<td>44</td>
<td>M</td>
<td>LAD</td>
<td>70%</td>
<td>35%</td>
<td>70%</td>
<td>38/13</td>
</tr>
<tr>
<td>30</td>
<td>36</td>
<td>M</td>
<td>RCA</td>
<td>85%</td>
<td>30%</td>
<td>85%</td>
<td>60/10</td>
</tr>
<tr>
<td>32</td>
<td>63</td>
<td>M</td>
<td>RCA</td>
<td>90%</td>
<td>25%</td>
<td>100%</td>
<td>60/10</td>
</tr>
<tr>
<td>42</td>
<td>51</td>
<td>M</td>
<td>LAD</td>
<td>75%</td>
<td>40%</td>
<td>40%</td>
<td>60/16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cx</td>
<td>90%</td>
<td>50%</td>
<td>80%</td>
<td>62/24</td>
</tr>
<tr>
<td>68</td>
<td>39</td>
<td>M</td>
<td>LAD</td>
<td>85%</td>
<td>60%</td>
<td>90%</td>
<td>35/10</td>
</tr>
</tbody>
</table>

Abbreviations: PTCA = percutaneous transluminal coronary angioplasty; RCA = right coronary artery; LAD = left anterior descending coronary artery; Cx = left circumflex coronary artery; CABG = coronary artery bypass grafting; MI = myocardial infarction.

Sensitivities and specificities for exercise electrocardiography and thallium scintigraphy were 0.59 and 0.67; it was 0.78 and 0.80, respectively, if patients with a submaximal stress were excluded. The values are within the range of 0.50–0.81 for the exercise ECG and 0.56–0.80 for thallium scintigraphy reported for patients who have one-vessel coronary disease.1,2 Thirteen of 20 patients (65%) had an abnormal exercise ECG before PTCA in the study of Hirzel et al.15 and 19 of 22 (86%) had an abnormal exercise ECG in the series reported by Cowley et al.18 The sensitivity of thallium scintigraphy was 88% and 80% in these two studies, respectively.

The sensitivity of exercise electrocardiography and thallium scintigraphy in a population referred for PTCA is influenced by the selection criteria. If only patients who have objective evidence of myocardial ischemia as determined by exercise electrocardiography and scintigraphy are selected, the sensitivity of both diagnostic tests will be proportionately greater. Variables such as the exercise ECG lead system21,22,24-26 and the accumulation, display and subsequent analysis of scintigraphic images27 also determine test sensitivity and may explain, in part, some of the interstudy differences.

Patients referred for PTCA are highly selected; many have one-vessel coronary disease, predominantly of the left anterior descending coronary artery. The patients who are selected usually require a stenosis that is proximal, concentric, not heavily calcified, and that does not include a major secondary branch. Our data confirm that the sensitivity of exercise electrocardiography and thallium scintigraphy in a population of patients referred for PTCA is similar to results obtained in a larger and more heterogeneous population of patients with a similar extent of coronary disease.38 An analysis of the exercise ECG, physiologic results and the scintigraphic data are indicated in the workup of patients before PTCA. The scintigram, when abnormal, is more precise than the exercise ECG in determining the area of myocardial ischemia, which is particularly useful in assessing restenosis in the dilated artery.

Serial Follow-up
The initial success rate of PTCA was 64% in our series of 70 patients, similar to the 60–65% reported by...
TABLE 2. (Continued)

<table>
<thead>
<tr>
<th>Rate-pressure product (10^3 units) When symptoms reap- peared</th>
<th>Maximum depth of ST-segment shift (mm)</th>
<th>Number of positive ECG leads When symptoms reap- peared</th>
<th>Subsequent evolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before</td>
<td>1 mo.</td>
<td>Before</td>
<td>1 mo.</td>
</tr>
<tr>
<td>19.95</td>
<td>17.02</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>17.19</td>
<td>24.19</td>
<td>2.8</td>
<td>2.2</td>
</tr>
<tr>
<td>19.50</td>
<td>19.04</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>20.57</td>
<td>36.54</td>
<td>31.31</td>
<td>0</td>
</tr>
<tr>
<td>16.20</td>
<td>30.45</td>
<td>30.24</td>
<td>0</td>
</tr>
<tr>
<td>16.52</td>
<td>34.00</td>
<td>22.82</td>
<td>5</td>
</tr>
<tr>
<td>16.20</td>
<td>32.76</td>
<td>17.66</td>
<td>1</td>
</tr>
<tr>
<td>14.10</td>
<td>31.50</td>
<td>21.00</td>
<td>2</td>
</tr>
<tr>
<td>19.72</td>
<td>35.20</td>
<td>35.70</td>
<td>2.4</td>
</tr>
<tr>
<td>19.80</td>
<td>38.28</td>
<td>16.80</td>
<td>1.6</td>
</tr>
</tbody>
</table>

The rate of restenosis in the first 6 months was 31% in the 39 patients who had a successful PTCA and repeat coronary angiography, slightly greater than the 19–23% reported in other series. The incidence of restenosis may have been increased by attempting PTCA in patients with fixed coronary lesions and variant angina. When the patients with variant angina were excluded, the rate of restenosis in the first 6 months in our series was 23% (seven of 30 patients). Progression of coronary disease in nondilated arteries did not occur in the 6-month interval after PTCA in this series. In two studies in which the natural history of coronary disease was determined by control angiography 12 and 18 months after randomization to medical therapy, the rate of disease progression was 21% and 29%, respectively. In the former study, disease progression was defined as a new stenosis ≥ 70% or total occlusion of a previous stenosis. In the latter study, four angiographic criteria were used. Disease progression was more frequent in the patients who had more extensive coronary disease. The data suggest that in the first 6–12 months after PTCA, persistence or development of an abnormal noninvasive test result is more likely to be the result of restenosis than evolution of coronary disease in nondilated arteries.

In most other reports on PTCA, noninvasive test results are not analyzed after the patients are subdivided into symptomatic and asymptomatic groups. Clinical symptoms are very important in evaluating serial changes in the angiographic status of the patient, especially when evaluating the diagnostic usefulness of noninvasive test results. In our symptomatic patients, serial comparison of the noninvasive test results provided objective evidence of restenosis in 89% of the patients (eight of nine). The ninth patient had a 95% right coronary stenosis, large intercoronary collaterals, and a normal exercise ECG and thallium scintigram. In the asymptomatic patients, the noninvasive test results permitted us to diagnose restenosis or residual disease in 20% of the patients (four of 20) who had control angiography, and in two of five patients after a second PTCA attempt. The use of treadmill work time and rate-pressure product in the serial evaluation of patients before and after PTCA was useful in distinguishing false-positive from true-positive results. Training effects, pharmacologic interventions and the exercise conditions and protocol must be considered before attributing differences in the latter two variables to changes in coronary anatomy.

In our series, 64% of abnormal thallium scintigrams (14 of 22) returned to normal 1 month after successful PTCA, compared with 100% in the series of Hirzel et al. Since the restenosis rate in both series were similar, the difference may be a function of the exercise protocol used, which was maximal at 1 month in our series and only submaximal in the study of Hirzel et al. In the latter study, the exercise test after PTCA was stopped at the same work load and duration of exercise as the test performed before PTCA.

Three patients in our series had a positive thallium scan at 1 month that became negative at 6 months at a similar rate-pressure product and treadmill time. The three patients all had single left anterior descending coronary disease and were taking no medication at the
FIGURE 5. Proximal stenoses of 75% in the left anterior descending coronary artery (LAD) and 90% in the left circumflex artery (Cx) were associated with an abnormal ECG (not shown) and thallium scintigram in this 51-year-old man (patient 42) in angina class III (table 2) (top left). The LAD stenosis was dilated to 40% and the Cx to 50%. One month after percutaneous transluminal coronary angioplasty (PTCA), the patient was asymptomatic and the exercise ECG and thallium scintigram were normal (top right). Five months later, symptoms recurred; the exercise ECG (not shown) and thallium scintigram became abnormal and repeat angiography revealed an 80% restenosis of the Cx (lower left). The Cx was redilated to 40%; the patient is symptom-free 1 month after the second PTCA and the exercise ECG and scintigram have returned to normal (lower right). LAO = left anterior oblique; AP = anteroposterior.
time of restudy. The control angiogram was similar after PTCA and at 6 months and no collateral circulation was observed. Coronary spasm might explain this finding, but is unlikely in the absence of exercise ECG abnormalities in the 14-lead ECG. Although Grünzig and colleagues observed improved caliber and smoothness from PTCA to the 6-month control angiogram, we did not perform coronary angiography at 1 month and thus cannot confirm a significant angiographic difference between 1 and 6 months in the three patients.

Clinical Implications

PTCA is considered an investigational procedure; thus, a control coronary angiogram would seem warranted after PTCA in asymptomatic patients until a larger clinical experience has accumulated. However, if our results are confirmed in a larger data pool, guidelines for repeat coronary angiography might be determined over the short term by the patient’s symptomatic status and the results of the exercise ECG and myocardial scintigram. Since noninvasive test results between 1 and 3 months are similar in asymptomatic patients and since restenosis, when it occurs, usually happens in the first 3 months, the exercise ECG and myocardial scintigram in asymptomatic patients could be performed at 3 months rather than sequentially at 1, 3 and 6 months. Asymptomatic patients who have an abnormal test after PTCA at a rate-pressure product similar to that before PTCA should be followed closely because restenosis is likely. In symptomatic patients, the noninvasive tests provide objective evidence of myocardial ischemia and help characterize symptoms. They also provide a baseline document for subsequent management and evaluation of treatment if a second PTCA attempt or subsequent bypass graft surgery is performed.

References

Exercise electrocardiography and myocardial scintigraphy in the serial evaluation of the results of percutaneous transluminal coronary angioplasty.

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