Exercise-Induced ST-Segment Depression in Patients Without Restenosis After Coronary Angioplasty: Relation to Preprocedural Impaired Left Ventricular Function

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**Background** ST-segment depression during exercise testing is frequently observed in the absence of restenosis after coronary angioplasty.

**Methods and Results** We studied the determinants of this phenomenon in 70 consecutive patients with unstable angina related to a single left anterior descending coronary artery lesion who had successful angioplasty without restenosis (<50% stenosis by quantitative angiography). We compared preangioplasty clinical, angiographic, and hemodynamic variables in the group with positive (ExT Pos, n=35; ST depression, 2.3±0.9 mm) and negative (ExT Neg, n=35; ST depression, 0.3±0.5 mm) results on exercise testing at follow-up angiography. At this time, minimal lumen diameter (1.7±0.4 mm) and mean residual stenosis (34±11%) in the ExT Pos group were not significantly different from the values (1.9±0.5 mm, 38±10%) in the ExT Neg group. Before angioplasty, the ExT Pos group had a lower ejection fraction (63±8% versus 68±9%, P<.05), more marked anterior hypokinesis estimated by the extent of anterior wall contraction on quantitative ventriculography (P<.05), and a greater end-systolic volume (30±11 versus 25±9 mL/m², P<.05) than the ExT Neg group. At follow-up angiography, regional anterior wall motion was normal in 68 patients (97%). Anterior hypokinesis before angioplasty was strongly associated (P<.01) with a positive exercise test at control (71% compared with 31% in patients with normal wall motion before angioplasty).

**Conclusions** In the absence of significant epicardial stenosis after angioplasty, ST-segment depression is strongly associated with the presence of preprocedural regional ventricular dysfunction that has recovered at follow-up angiography. (Circulation. 1994;90:148-155.)

**Key Words** • restenosis • contractility • angioplasty • exercise testing

Exercise-induced ST-segment depression occurring in patients with atherosclerotic obstructive coronary disease is considered to be related to exercise-induced myocardial ischemia. However, when exercise testing is performed in patients who have successfully undergone percutaneous transluminal coronary angioplasty for a single epicardial coronary stenosis, significant ST-segment depression may occur in the documented absence of restenosis; such a response is frequently designated as false-positive response. The pathophysiological significance of ST-segment depression in this context is not clear, although many possible explanations have been proposed.

It was recently shown that the persistence of ST-segment depression on exercise testing in the absence of restenosis after angioplasty performed in patients who had stable angina and one-vessel disease was not related to an abnormality of vasomotor response at the dilated site. On the basis of these observations, El-Tamimi et al suggested that ST-segment depression in this setting might be related to functional alterations in small coronary vessels.

In our institution, where we perform systematic angiographic follow-up in all patients after successful coronary angioplasty, we have observed that exercise-induced ST-segment depression in the absence of restenosis is particularly common in patients who undergo angioplasty in the setting of unstable angina. To study potential determinants of this false-positive exercise response, we identified a consecutive series of patients with unstable angina related to a single narrowing on the left anterior descending coronary artery. We compared clinical and hemodynamic variables, quantitative assessments of coronary diameters, and quantitative assessments of global and regional ventricular function in the subgroup that did and the subgroup that did not develop ST-segment depression on exercise testing performed at the time of follow-up angiography.

**Methods**

We identified a consecutive group of patients who presented with unstable angina related to an isolated left anterior descending stenosis, who had no evidence of recent or remote myocardial infarction, who underwent successful percutaneous transluminal coronary angioplasty in our institution, and who had exercise testing at the time of a control coronary angiogram that documented the absence of restenosis. We compared preangioplasty clinical, hemodynamic, and angiographic variables in the subgroup of patients who developed exercise-induced ST-segment depression (ExT Pos group) and

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in the subgroup of patients in whom no significant ST-
depression occurred on exercise (ExT Neg group).

**Patients**

We identified 70 consecutive patients (55 men and 15 
women) who between January 1987 and September 1991 
underwent successful angioplasty of an isolated proximal 
(before the origin of the first large septal perforating branch) 
or middle (between the origin of the first large septal 
perforating branch and the origin of the second diagonal branch) 
left anterior descending stenosis and who at angiographic 
follow-up 6 months after the last angioplasty procedure had 
not developed restenosis as assessed with use of quantitative 
coronary angiography. Unstable angina was defined according 
to the criteria proposed by Braunwald; all the patients were in 
class B. The time delay between angioplasty and the final 
follow-up angiographic evaluation varied depending on 
whether the occurrence of restenosis necessitated the 
performance of repeated procedures. Thirty-seven patients had 
dergone one angioplasty; the remainder had undergone two (18 
patients), three (7 patients), or four (8 patients) procedures.

Twenty-eight other patients who underwent angioplasty 
during the same period and fulfilled the criteria outlined above 
were excluded from the study because information relating to 
one or more of the variables studied was unavailable or 
uninterpretable. These included 18 patients in whom the 
ventriculogram before or after angioplasty was unsuitable for 
quantitative analysis due to the occurrence of multiple extra-
systoles, 10 patients in whom the exercise test was uninter-
pretable because it was submaximal or were taking medication 
that is known to render the interpretation of the exercise test 
unreliable.

**Exercise Testing**

All the patients had a standard maximal Bruce protocol 
exercise test. All the tests were performed with use of a 
computerized exercise-ECG system (Case 12, Marquette Elec-
tronics) after antianginal medication had been discontinued 
for more than 48 hours and within 2 weeks of the follow-up 
angiogram that demonstrated the absence of restenosis.

ST-segment depression was considered significant if 0.1 mV 
or more of horizontal or downsloping ST-segment depression 
measured 0.06 second after the J point occurred compared 
with the rest baseline value. The rate-pressure product (heart 
rate x systolic blood pressure) was calculated at rest, at 1-mm 
ST-segment depression (for positive tests only), and at peak 
exercise.

**Quantitative Coronary Angiographic Evaluation of 
Angioplasty Procedure**

Coronary angioplasty was performed according to the stan-
dard technique in our laboratory, as previously described.6 
Angiograms were performed in at least two projections before 
angioplasty and immediately after angioplasty. Measurements 
were performed on end-diastolic frames from angiograms 
obtained 2 minutes after the intracoronary administration of 
isosorbide dinitrate (2 mg) with use of the CAESAR (Computer-
Assisted Evaluation of Stenosis and Restenosis) system.7 The 
validation of this system and the interobserver and intrab-
server variations of measurements obtained under routine 
clinical conditions have been previously reported.7 All the 
measurements were performed by one observer who was 
unaware of the design of the study. A procedure was consid-
ered to be successful if the residual stenosis at the dilated site, 
immediately after the procedure, was <50% without major 
complication. Restenosis was defined as the recurrence of 
>50% narrowing at the dilated site on follow-up angiography. 
By definition, all the study patients had successful procedures 
without restenosis on the follow-up angiogram performed after 
the last angioplasty procedure.

**Quantitative Evaluation of Global and Regional 
Left Ventricular Function**

**Hemodynamic Variables**

Ventricular function was evaluated on single-plane right 
anterior oblique projection (30°). The left ventricular contours 
on end-systolic and end-diastolic frames were manually traced 
by one blinded observer and then digitized. The left ventricu-
lar end-systolic volume index (LVESVI, mL/min), left-ven-
tricular end-diastolic volume index (LVEDVI, mL/min), and 
ejection fraction (EF, percent shortening) were calculated 
according to the area-length method, with use of the formula 
described by Kennedy et al.8 Segmental wall motion was measured 
with the radial method, using a center located at 
69% of a line joining the upper edge of the aorta to the left 
ventricular apex at end systole.9 A regional wall motion index 
(RWMI, percent shortening) was calculated for each segment 
with use of the following formula: RWMI=100×[(end-diastolic 
radius minus end-systolic radius)/end-diastolic radius] (Fig 1). 
To compare values for regional anterior and apical wall 
function before angioplasty with values at follow-up angiogra-
phy, we used the values for the second (RWMI2), fourth 
(RWMI4), and sixth (RWMI6) radial segments as an index of 
anterior wall function and the values for the eighth (RWMI8) 
and 10th (RWMI10) radial segments as an index of apical 
function. The normal range for EF and for each of the RWMI 
was calculated using ventriculograms performed during rou-
tine coronary angiography in 30 subjects with atypical chest 
pain who had no evidence of coronary artery disease or other 
cardiovascular pathology. The normal range for EF was 
71±7%. The normal range for each of the five RWMI studied 
was RWM1, 48±12%; RWM2, 56±13%; RWM3, 55±13%; 
RWM4, 51±13%; and RWM5, 42±14%. In the study popula-
tion, the wall motion index for an individual segment was 
considered to be normal if the value lay within 2 SD of the 
equivalent mean value in the control population. Anterior wall 
function was considered to be hypokinetic if the wall motion 
indexes for two or more of the five segments studied lay ≥2 SD 
below the normal range. The baseline values for left ventricular 
diastolic pressure (LVDP, mm Hg), left ventricular systolic 
pressure (LVSP, mm Hg), and aortic diastolic pressure (AoDP, 
mm Hg) were calculated before injection of contrast as the 
mean of 10 consecutive cycles with use of a computerized 
system (HEMO-TRACE 3).

**Statistical Analysis**

Values are given as mean±SD. The data were initially 
analyzed with ANOVA for repeated measures. If significant 
differences were detected, comparisons within groups were 
performed with use of paired Student’s t tests. Between-group 
comparisons were performed with use of unpaired Student’s t 
tests. Differences between proportions were assessed by χ2 
analysis. The statistical analyses were performed by the De-
partment of Biostatistics (University of Lille) on SAS software 
(version 6.09). A value of P<.05 was considered to indicate 
statistical significance.

**Results**

**Clinical and Demographic Data**

Mean age and the distribution of risk factors for coronary disease did not differ significantly in patients 
who had positive (ExT Pos group, n=35) or negative 
(ExT Neg group, n=35) results on exercise testing 
(Table 1). The mean interval from the onset of symp-
toms to the angioplasty procedure, the mean time from 
angioplasty to the final follow-up angiogram that docu-
mented the absence of restenosis, and the mean number 
of procedures (1.8) did not differ significantly between 
the groups.
Results of Exercise Testing

The mean time from the performance of exercise testing to the follow-up angiogram that documented the absence of restenosis did not differ significantly between the groups (Table 1). The mean maximal ST-segment depression in the patients with positive results on exercise testing, who made up 50% of the total population (ExT Pos group, n=35), was 2.3±0.9 mm. The mean maximal ST-segment depression in the patients with negative results on exercise testing (ExT Neg group, n=35) was 0.3±0.5 mm. The lead that showed the most marked ST-segment depression was a lateral lead (V4, V5, V6) in 59 patients (84%). Ten of the patients in the ExT Pos group developed atypical chest pain during exercise. The symptoms during the exercise test were unlike the chest pain experienced during the initial admission for unstable angina; no exercise test was terminated because of atypical chest pain. There were no significant differences between the groups with respect to exercise duration, rate-pressure product at rest, or rate-pressure product at peak exercise (Table 2).

Table 1. Baseline Clinical and Angiographic Data

<table>
<thead>
<tr>
<th></th>
<th>Total Population (n=70)</th>
<th>ExT Neg group (n=35)</th>
<th>ExT Pos group (n=35)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>57±9</td>
<td>56±9</td>
<td>59±8</td>
<td>NS</td>
</tr>
<tr>
<td>Women, n (%)</td>
<td>15 (21)</td>
<td>7 (20)</td>
<td>8 (23)</td>
<td>NS</td>
</tr>
<tr>
<td>Smokers, n (%)</td>
<td>35 (50)</td>
<td>16 (46)</td>
<td>19 (54)</td>
<td>NS</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>23 (33)</td>
<td>14 (40)</td>
<td>9 (26)</td>
<td>NS</td>
</tr>
<tr>
<td>Diabetes, n (%)</td>
<td>13 (19)</td>
<td>9 (26)</td>
<td>4 (11)</td>
<td>NS</td>
</tr>
<tr>
<td>Hypercholesterolemia, n (%)</td>
<td>46 (66)</td>
<td>23 (66)</td>
<td>23 (66)</td>
<td>NS</td>
</tr>
<tr>
<td>Family history of cardiovascular disease, n (%)</td>
<td>37 (53)</td>
<td>19 (54)</td>
<td>18 (51)</td>
<td>NS</td>
</tr>
<tr>
<td>Mean time, d</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From onset of symptoms to the angioplasty</td>
<td>105±94</td>
<td>110±119</td>
<td>96±109</td>
<td>NS</td>
</tr>
<tr>
<td>From angioplasty to final angiography</td>
<td>368±89</td>
<td>367±248</td>
<td>372±167</td>
<td>NS</td>
</tr>
<tr>
<td>From exercise test to final angiography</td>
<td>3.6±3.4</td>
<td>3.5±5</td>
<td>3.6±4.8</td>
<td>NS</td>
</tr>
<tr>
<td>Stenosis Location, n</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Proximal LAD</td>
<td>36</td>
<td>19</td>
<td>17</td>
<td>NS</td>
</tr>
<tr>
<td>Middle LAD</td>
<td>34</td>
<td>16</td>
<td>18</td>
<td>NS</td>
</tr>
</tbody>
</table>

ExT Neg group indicates patients without significant ST-segment depression on exercise; ExT Pos group, patients with significant ST-segment depression on exercise; diabetes, fasting blood sugar >6.8 mmol/L; hypercholesterolemia, cholesterol >240 mg/dL; proximal LAD, lesion in left anterior descending coronary artery before the first large septal perforator; and middle LAD, lesion in left anterior descending coronary artery after first large septal and before first diagonal. Values are given as mean±SD when appropriate; values in parentheses are percentages of the total numbers in each group.
TABLE 2. Results of Exercise Testing

<table>
<thead>
<tr>
<th></th>
<th>Total Population (n=70)</th>
<th>ExT Neg group (n=35)</th>
<th>ExT Pos group (n=35)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST depression, mm</td>
<td>–1.3±0.9</td>
<td>–0.3±0.5</td>
<td>–2.3±0.9</td>
<td>*</td>
</tr>
<tr>
<td>Chest pain, n (%)</td>
<td>10 (14)</td>
<td>0</td>
<td>10 (28)</td>
<td>*</td>
</tr>
<tr>
<td>Rate-pressure product at rest</td>
<td>10 758±2791</td>
<td>10 812±2484</td>
<td>10 703±3103</td>
<td>NS</td>
</tr>
<tr>
<td>Time to 1-mm ST depression, min</td>
<td>...</td>
<td>...</td>
<td>6.3±3</td>
<td>...</td>
</tr>
<tr>
<td>Rate-pressure product at 1-mm ST depression</td>
<td>...</td>
<td>...</td>
<td>22 898±5536</td>
<td>...</td>
</tr>
<tr>
<td>Total exercise time, min</td>
<td>8.8±3</td>
<td>9.2±2.5</td>
<td>8.5±2.3</td>
<td>NS</td>
</tr>
<tr>
<td>Rate-pressure product at peak exercise</td>
<td>28 292±5718</td>
<td>29 125±4852</td>
<td>27 535±6386</td>
<td>NS</td>
</tr>
</tbody>
</table>

ExT Neg group indicates patients without significant ST-segment depression on exercise; ExT Pos group, patients with significant ST-segment depression on exercise; and rate-pressure product, heart rate (beats per minute)×systolic blood pressure (mm Hg). Values are given as mean±SD where appropriate.

*P<.001 ExT Pos group vs ExT Neg group.

Quantitative Coronary Angiographic Analysis

The proportion of lesions that were located in the proximal or mid left anterior descending artery did not differ significantly between the groups. Mean values for percent stenosis severity before and immediately after angioplasty and at follow-up angiography (73±11%, 34±8%, and 34±11%, respectively) in the ExT Pos group did not differ significantly from the values in the ExT Neg group (78±12%, 31±11%, and 38±10%, respectively) (Table 3). The mean minimal luminal diameter at follow-up angiography in the ExT Pos group (1.70±0.40 mm) was not significantly different from the value in the ExT Neg group (1.90±0.50 mm) (Table 3).

Quantitative Analysis of Global and Regional Ventricular Function

The mean EF in the total study population 6 months after the final, ultimately successful, angioplasty (70±7%) was significantly (P<.001) higher than the value before angioplasty (65±8%) (Table 4). At follow-up angiography, 68 patients (97%) had EFs within the normal range for our laboratory. Regional anterior wall motion indexes followed a similar pattern. RWMs through RWMs increased by a mean of 29% between angioplasty and follow-up. Of the hemodynamic variables studied, only LVSP and LVESVI were significantly different at follow-up angiography compared with preangioplasty values (Table 4). LVESP at follow-up angiography (140±23 mm Hg) was significantly (P<.001) higher than that (131±22 mm Hg) before angioplasty. The LVESVI at follow-up angiography (24±10 mL/m²) was significantly (P<.001) less than that (28±10 mL/m²) before angioplasty.

Comparison Between Groups With and Without Exercise-Induced ST-Segment Depression

Before angioplasty, the mean EF (63±8%) in the ExT Pos group (n=35) was significantly (P<.05) less than that (68±9%) in the ExT Neg group (n=35). However, mean EF at final angiographic evaluation in the ExT Pos group (69±8%) was not significantly different than that for the ExT Neg group (71±6%). Thus, although global EF had been significantly lower in the ExT Pos group than in the ExT Neg group before angioplasty, there was no difference between groups at the final angiographic evaluation after successful angioplasty (Table 5). This reflects the fact that although the mean EF in the ExT Pos group increased significantly (P<.01) from 63±8% before angioplasty to 69±8% at follow-up angiography, the mean EF in the ExT Neg group did not change significantly during this time.

Segmental analysis of left ventricular function demonstrated that the ExT Pos group had a significant impairment of anterior wall motion before angioplasty compared with the ExT Neg group. The extent of fractional shortening in the anterior wall segments we

TABLE 3. Quantitative Angiographic Data

<table>
<thead>
<tr>
<th></th>
<th>ExT Pos group (n=35)</th>
<th>ExT Neg group (n=35)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angioplasty</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenosis before angioplasty, %</td>
<td>73±11</td>
<td>78±12</td>
<td>NS</td>
</tr>
<tr>
<td>Stenosis after angioplasty, %</td>
<td>34±8</td>
<td>31±11</td>
<td>NS</td>
</tr>
<tr>
<td>Follow-up angiography</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stenosis severity, %</td>
<td>34±11</td>
<td>38±10</td>
<td>NS</td>
</tr>
<tr>
<td>Minimum luminal diameter, mm</td>
<td>1.7±0.4</td>
<td>1.9±0.5</td>
<td>NS</td>
</tr>
</tbody>
</table>

ExT Pos group indicates patients with significant ST-segment depression on exercise; ExT Neg group, patients without significant ST-segment depression on exercise. Values are given as mean±SD.
TABLE 4.  Contractility Indexes and Hemodynamic Data Before Angioplasty and at Follow-up Angiography

<table>
<thead>
<tr>
<th></th>
<th>Before Angioplasty</th>
<th>Follow-up Angiography</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ExT Neg group</td>
<td>ExT Pos group</td>
</tr>
<tr>
<td></td>
<td>(n=35)</td>
<td>(n=35)</td>
</tr>
<tr>
<td>EF, %</td>
<td>68±9</td>
<td>63±8§</td>
</tr>
<tr>
<td>RWM1, %</td>
<td>43±14</td>
<td>38±14</td>
</tr>
<tr>
<td>RWM2, %</td>
<td>50±15</td>
<td>41±16§</td>
</tr>
<tr>
<td>RWM3, %</td>
<td>48±15</td>
<td>38±18§</td>
</tr>
<tr>
<td>RWM4, %</td>
<td>44±14</td>
<td>32±18§</td>
</tr>
<tr>
<td>RWM5, %</td>
<td>33±14</td>
<td>25±16§</td>
</tr>
<tr>
<td>HR, bpm</td>
<td>72±12</td>
<td>69±10</td>
</tr>
<tr>
<td>LVEDP, mm Hg</td>
<td>13±5</td>
<td>15±7</td>
</tr>
<tr>
<td>LVSP, mm Hg</td>
<td>135±22</td>
<td>128±23</td>
</tr>
<tr>
<td>AoDP, mm Hg</td>
<td>74±13</td>
<td>69±13</td>
</tr>
<tr>
<td>LVESVI, mL/m²</td>
<td>25±9</td>
<td>30±11§</td>
</tr>
<tr>
<td>LVEDVI, mL/m²</td>
<td>86±21</td>
<td>80±21</td>
</tr>
</tbody>
</table>

ExT Neg group indicates patients without significant ST-segment depression on exercise; ExT Pos group, patients with significant ST-segment depression on exercise; EF, ejection fraction; RWM, through RWMn, regional wall motion indexes, expressed as percentage shortening; HR, heart rate; bpm, beats per minute; LVEDP, left ventricular end-diastolic pressure; LVSP, left ventricular systolic pressure; AoDP, aortic diastolic pressure; LVESVI, left ventricular end-systolic volume index; and LVEDVI, left ventricular end-diastolic volume index. Values are given as mean±SD.

*P<.05, †P<.01, ‡P<.001 before angioplasty vs at final angiographic evaluation in the same group.

§P<.05, †P<.01 ExT Pos vs ExT Neg group.

studied is detailed in Fig 2 and Table 5. The percent fractional shortening on the ventriculogram obtained before angioplasty was significantly (P<.05) lower in four of the five segments studied in the ExT Pos group compared with the ExT Neg group. In the ExT Neg group, percent fractional shortening was within the normal range in all anterior wall segments studied on the ventriculogram obtained before angioplasty; at follow-up angiography, all the measurements were again within the normal range and had not changed significantly compared with before angioplasty. In the ExT Pos group, there was a significant improvement in percent fractional shortening in all anterior wall segments between the initial (preangioplasty) and follow-up (after successful angioplasty without restenosis) ventriculograms. The extent of this improvement ranged from 31% in RWM1 (P<.01) to 53% in RWM4 (P<.01), and all values were within the normal range. The relation of anterior wall function before angioplasty to the occurrence of a positive or negative exercise test at control angiography was assessed by dividing the patients into two groups based on the quantitative assessment of anterior wall function. Anterior wall contractility before angioplasty was classified as normal (n=36) if the percent fractional shortening was within the normal range for all five anterior wall segments studied. Anterior wall contractility before angioplasty was classified as depressed (n=34) if the percent fractional shortening was less than normal for two or more of the segments studied. The presence of depressed contractility before angioplasty was significantly (P<.01) associated with the occurrence of significant ST-segment depression on exercise testing at control angiography (Table 6).

The ExT Pos group also had a significantly (P<.05) greater end-systolic volume (LVESVI, 30±11 mL/m²) before angioplasty than the ExT Neg group (25±9 mL/m²). This parameter did not differ significantly between groups at follow-up angiography. This was due to the significant (P<.05) decrease in LVESVI from 30±11 to 25±12 mL/m² that occurred in the ExT Pos group between angioplasty and follow-up; the LVESVI in the ExT Neg group did not change significantly during this time. The other hemodynamic parameters studied (Table 5) did not differ significantly between groups either before angioplasty or at follow-up angiography.

Discussion

The major and original finding of this study is that exercise-induced ST-segment depression on exercise testing in patients without restenosis after successful one-vessel coronary angioplasty is strongly associated with the presence of localized hypokinesis before angio-
plasty in the territory supplied by the dilated vessel that has regained normal contractility after the procedure.

Treadmill exercise testing is commonly undertaken in patients who have undergone coronary angioplasty. The information derived from such testing in conjunction with the symptomatic status of the patient is often used to assess the likelihood that restenosis has occurred. A limitation to the use of exercise testing in the assessment of restenosis in patients who have undergone one-vessel angioplasty is related to the low sensitivity and specificity of ST-segment depression in this population as a predictor of significant coronary stenosis.\textsuperscript{1} The patients in this study all had dilation of one lesion in the left anterior descending coronary artery and had not developed restenosis at the time of final exercise testing. Thus, considerations related to the specificity and sensitivity of exercise testing cannot be invoked as an explanation for the results. In addition, in this study we specifically excluded patients who were taking medication or who had conditions that are known to be associated with false-positive responses to exercise. Furthermore, it is not clear that the occurrence of ST-segment depression on exercise testing in the absence of restenosis in this population is truly a false-positive response; it is equally possible that it reflects myocardial ischemia occurring in the absence of significant epicardial stenosis and related to a defect in microvascular function such as has been documented in patients with syndrome X.\textsuperscript{10}

ST-segment depression on follow-up exercise testing in patients who undergo angioplasty for one-vessel disease may be related to the presence of a physiologically significant stenosis at the dilated site. Such a stenosis may reflect an inadequate primary dilation, which we have shown to be relatively common and usually unappreciated by the operator who performed the procedure.\textsuperscript{2} Second, it may result from the occurrence of restenosis at the dilated site. Third, it may be related to the development of a new lesion at an undilated site. All of these possibilities were excluded in the present study.

Many studies\textsuperscript{11,12} have shown that the physiological importance of a coronary stenosis is not necessarily related to the percent luminal narrowing at the site of the lesion. For example, it is obvious that a given percent stenosis in a 4-mm vessel would not have the same hemodynamic significance as the same percent stenosis in a 2-mm vessel. Thus, the occurrence of exercise-induced ST-segment depression in some but not in other patients without restenosis might be related to a difference in the absolute diameter of the angiographically normal nondilated vessel between groups. Such a difference could result from the presence of occult atherosclerosis in angiographically smooth vessels; indeed, recent intravascular ultrasound studies\textsuperscript{13,14} demonstrated that vessel segments that appear normal on angiography in patients with focal epicardial stenosis have ultrasonic characteristics compatible with the presence of diffuse atherosclerosis. The presence or absence of ST-segment depression on exercise might also be related to differences in the absolute minimal residual lumen diameter at the dilated site. The results of the present study exclude these hypotheses in our patients because mean percent residual stenosis at the dilated
site and mean minimal lumen diameter at the dilated site did not differ between groups with positive or negative results on exercise testing.

A recent study has suggested that ST-segment depression occurring 1 week after angioplasty in the absence of restenosis may reflect functional alterations in small coronary vessels.4 Such alterations might be present before angioplasty or could be related to the procedure itself. The natural history of ST-segment depression occurring early after angioplasty has not been well defined. It has been suggested13 that such ST-segment depression is a predictor of subsequent restenosis. It is thus unclear whether the ST-segment depression in our patients 6 months after successful angioplasty has the same pathophysiological basis as that occurring after the procedure. A sequential study10 of coronary flow reserve immediately after and at 6 months after coronary angioplasty demonstrated an impairment of coronary flow reserve just after the procedure that is related to an increase in resting blood flow that had resolved at 6 months. However, the relation between coronary flow reserve at 6 months and the occurrence of exercise-induced ST-segment depression in the absence of restenosis has not been specifically examined. The results of the present study are compatible with the hypothesis that alterations in the functional characteristics of small coronary vessels present before angioplasty or related to the performance of angioplasty may persist on a long-term basis.17 Experimental studies18-20 show that anatomic or functional alterations in microvascular function are present in hibernating21,22 or stunned myocardium.23 Such alterations in microvascular function probably are also present in the clinical syndrome of unstable angina. Although the anatomic microvascular changes are rapidly reversed when normal basal flow is restored,24,25 the functional alterations persist for much longer periods.17 By limiting coronary flow reserve, such functional alterations could be associated with positive results on exercise testing due to exercise-induced myocardial ischemia despite the relief of epicardial mechanical obstruction by angioplasty.

An alternative explanation for exercise-induced ST-segment depression in this population is that it reflects changes in the electrical properties of myocardial cells or metabolic adaptations related to prior episodes of unstable angina even when myocardial function at rest has normalized. Further studies are needed to elucidate these hypotheses.

**Study Limitations**

Because exercise was not performed during coronary angiography, we cannot exclude the possibility that exercise-induced ST-segment depression is related to the occurrence of coronary vasoconstriction during exercise. This, however, is unlikely as none of the patients had a history suggestive of variant angina; furthermore, exercise-induced coronary spasm is more commonly associated with ST-segment elevation than with ST-segment depression during exercise testing. Second, because the left ventriculogram was obtained at rest, we cannot determine whether the ST-segment depression that we observed during exercise reflects alterations in left ventricular function on exercise.

**Conclusions**

Our results confirm the findings of several previous studies26-28 that demonstrated an improvement in the function of myocardium in the territory supplied by a significant coronary stenosis after successful revascularization. The major and novel finding of this study is that the occurrence of a false-positive exercise response after revascularization by angioplasty is directly related to the presence of preprocedural impaired left ventricular dysfunction. The pathophysiological mechanism of this finding remains to be elucidated.

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**References**

Exercise-induced ST-segment depression in patients without restenosis after coronary angioplasty. Relation to preprocedural impaired left ventricular function.
J P Beregi, C Bauters, E P McFadden, P Quandalle, M E Bertrand and J M Lablanche

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