Role of Coronary Collateral Vessels During Transient Coronary Occlusion During Angioplasty Assessed by Hemodynamic, Electrocardiographic and Metabolic Changes

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The clinical role of collateral vessels was evaluated during transient coronary occlusion by percutaneous transluminal coronary angioplasty in 22 patients with (8) and without (14) collateral vessels. Coronary occlusion pressure, the ratio of mean coronary occlusion pressure to mean aortic pressure and myocardial perfusion pressure at 40 s of balloon inflation were significantly higher in patients with than in patients without collateral vessels. The changes in left ventricular systolic and end-diastolic pressure, maximal rate of rise of left ventricular pressure (peak dP/dt) and maximal rate of fall of left ventricular pressure were less in patients with than in patients without collateral vessels.

Myocardial lactate was produced in patients without collateral vessels but not in those with such vessels. Marked ST segment elevation in the electrocardiogram occurred in patients without collateral vessels but either ST segment depression or mild ST segment elevation was observed in patients with collateral vessels.

This study indicates that collateral vessels limit myocardial ischemia during coronary occlusion, probably as a result of increased myocardial perfusion pressure.

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Percutaneous transluminal coronary angioplasty results in myocardial ischemia during balloon inflation (10). Therefore, coronary angioplasty provides a unique opportunity to study the function of collateral vessels in the setting of sudden coronary occlusion in conscious patients. Thus, we studied the effect of coronary collateral vessels on the electrocardiographic (ECG), hemodynamic and metabolic changes during coronary angioplasty in patients with coronary artery disease.

Methods

Study patients. We prospectively studied 22 patients undergoing elective coronary angioplasty for treatment of angina pectoris. The following inclusion criteria were used: 1) Single vessel coronary artery disease with isolated fixed stenosis in the proximal half of the left anterior descending coronary artery; 2) normal regional and global left ventricular systolic function; and 3) no conduction disturbance or ST segment abnormalities that would preclude ECG assessment of ischemia. Informed consent approved by our Institutional Review Board was obtained from all patients. The 22 patients were classified into two groups according to the...
presence or absence of collateral vessels. Group A consisted of 7 men and 1 woman (mean age 56 years) with collateral vessels and Group B consisted of 13 men and 1 woman (mean age 54 years) without collateral vessels. The location of the lesions undergoing coronary angioplasty was similar in the two groups.

**Catheterization procedure.** All patients received dipyridamole (150 mg orally), aspirin (60 mg orally), isosorbide dinitrate (15 mg orally) and nifedipine (30 mg orally) for 3 days before coronary angioplasty. All received a continuous infusion of intravenous nitroglycerin at a dose of 0.2 μg/kg per min, beginning at least 10 min before the first balloon inflation, and 10,000 U of heparin was administered intravenously at the beginning of the first balloon inflation. No intracoronary nitroglycerin was administered before the first balloon inflation.

The presence of collateral vessels was evaluated by coronary arteriography, which was performed immediately before the first balloon inflation. The grade of collateral vessels was assessed according to the scale reported by Rentrop et al. (11). Briefly, grade 0 = no visible filling of any collateral vessels, grade 1 = filling by means of collateral vessels of side branches of the vessel being dilated but without any dye reaching the epicardial segment of that vessel, grade 2 = partial filling by way of collateral vessels of the epicardial segment of the vessel being dilated and grade 3 = complete filling of the vessel being dilated. Gruentzig angioplasty catheters were used in this study. The distal catheter lumen and the guiding catheter were connected to Hewlett-Packard transducers by way of fluid-filled tubing. The catheter lumen was flushed regularly and frequently.

Coronary occlusion pressure was defined as the pressure recorded from the distal lumen of the balloon catheter during the balloon inflation. Coronary occlusion pressure was also expressed as a fraction of mean aortic pressure to eliminate the influence of the absolute proximal systolic pressure (12). The myocardial perfusion pressure during balloon inflation was defined as coronary occlusion pressure minus left ventricular diastolic pressure. This calculation was done by means of planimetry. A micromanometer-tipped catheter was inserted into the left ventricle through the left femoral artery. Ejection fraction was calculated by a modified area-length method (13). A 6F National Institutes of Health catheter was introduced from the right antecubital vein into the coronary venous system and was advanced to the great cardiac vein. Lactate samples were obtained at 40 s of balloon inflation and the transmyocardial lactate extraction ratio was calculated. The catheter could not be inserted into the great cardiac vein in one patient in Group A and two patients in Group B.

Electrocardiogram. The ECG in the standard 12 leads was continuously recorded during balloon inflation using X-ray transparent carbon-fiber electrodes. The lead showing the most prominent ST segment shift in the precordial leads was chosen, and the magnitude of ST segment shift was measured at 60 ms after the J point. All measurements were performed at the first balloon inflation and balloon inflation was maintained for 40 s.

**Statistical analysis.** Student’s unpaired t test was used for comparisons within the two groups. The results were expressed as mean values ± SEM. A p value <0.05 was considered statistically significant.

### Table 1. Clinical Characteristics of 22 Patients

<table>
<thead>
<tr>
<th></th>
<th>Group A (n = 8)</th>
<th>Group B (n = 14)</th>
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</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>56</td>
<td>54</td>
</tr>
<tr>
<td>Range</td>
<td>46 to 72</td>
<td>42 to 74</td>
</tr>
<tr>
<td>Gender (men/women)</td>
<td>7/1</td>
<td>13/1</td>
</tr>
<tr>
<td>Vessel undergoing PTCA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(AHA class)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Segment 6</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Segment 7</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Percent stenosis of lesion dilated</td>
<td>86 ± 1</td>
<td>79 ± 2</td>
</tr>
<tr>
<td>Ejection fraction (%)</td>
<td>71 ± 2</td>
<td>72 ± 2</td>
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AHA = American Heart Association; PTCA = percutaneous transluminal coronary angioplasty.

### Results

**Characteristics of the patient groups (Table 1).** The ejection fraction, left ventricular systolic pressure, left ventricular end-diastolic pressure, mean aortic pressure, maximal rate of rise of left ventricular pressure (peak dp/dt), maximal rate of fall of left ventricular pressure (negative peak dp/dt) and heart rate before the first balloon inflation did not significantly differ between Group A (with collateral vessels) and group B (without collateral vessels). The severity of stenosis before coronary angioplasty was significantly greater in Group A than in Group B (p < 0.05). Of the eight patients in group A, two showed grade 1 collateral vessels, one showed grade 3 vessels and five showed grade 2 vessels.

**Hemodynamic, electrocardiographic and metabolic changes.** The coronary occlusion pressure at 40 s of balloon inflation was higher in Group A than in Group B (Fig. 1) and the difference was significant (Fig. 2). The ratio of mean coronary occlusion pressure to mean aortic pressure at 40 s of balloon inflation was also significantly higher in Group A than in Group B (0.50 ± 0.02 versus 0.31 ± 0.03, p < 0.01). The myocardial perfusion pressure at 40 s of balloon inflation was 28.4 ± 2.3 mm Hg in Group A and 11.6 ± 1.9 mm Hg in Group B; this was a significant difference (Fig. 3). The changes in left ventricular systolic pressure, left ventricular end-diastolic pressure, peak dp/dt and negative peak dp/dt from immediately before balloon inflation to 40 s of balloon
Figure 1. Coronary occlusion pressure (COP) immediately before balloon inflation (left) and 40 s after balloon inflation (right) in a patient with collateral vessels (upper) and one without collateral vessels (lower). Electrocardiogram (ECG), aortic pressure (AO), left ventricular pressure (LVP) measured with a high fidelity tip manometer, its first derivative (dp/dt) and distal coronary pressure (DS) are also depicted. The coronary occlusion pressure at 40 s of balloon inflation is significantly higher in the patient with collateral vessels than in the patient without collateral vessels.

Figure 2. Coronary occlusion pressure at 40 s of balloon inflation in 8 patients with and 14 without collateral vessels (C).

inflation were significantly less in Group A than in Group B (Fig. 4).

The ST segment of the ECG at 40 s of balloon inflation was elevated in all patients in Group B (0.23 ± 0.02 mV) but in Group A, ST segment depression was observed in three patients and only mild ST segment elevation was noted in the remaining five.

Lactate samples were collected in 7 patients in Group A and 12 patients in Group B. The transmyocardial lactate extraction ratio at 40 s of balloon inflation was 21.4 ± 5.7% in Group A and −7.5 ± 2.6% in Group B. Lactate was produced in Group B but not in Group A (Fig. 5).

During the balloon inflation, 2 of the 8 patients in Group A and 8 of the 14 patients in Group B had chest pain.

Discussion

The results of this study support the concept that, in patients with ischemic heart disease, coronary collateral vessels can be physiologically important and may prevent or alleviate myocardial ischemia. Collateral vessels limited myocardial ischemia as assessed by hemodynamic, ECG and metabolic changes during transient coronary occlusion, although complete protection of myocardial ischemia during coronary occlusion was not obtained. Collateral vessels preserved not only regional left ventricular function as assessed by the extent of new ventricular asynergy, as demonstrated by Cohen and Rentrop (14), but also global left ventricular function as assessed by left ventricular systolic and diastolic function.

Coronary occlusion pressure and myocardial perfusion pressure. During abrupt coronary occlusion, coronary occlusion pressure in the left anterior descending coronary artery was higher in patients with collateral vessels than in those without. We used the coronary occlusion pressure as an index of collateral circulation. By occluding the proximal vessel and therefore eliminating anterograde flow, the distal pressure is determined by the capillary resistance, right atrial filling pressure, left ventricular wall tension and mainly collateral flow (15). Gregg et al. (16) first demonstrated that level coronary occlusion pressure was an indication of the collateral circulation. Eng and Kirk (17) also demonstrated
in an animal study that the coronary occlusion pressure reflected the coronary flow; other investigators (18,19) showed that there was a significant positive relation between coronary occlusion pressure measured during coronary bypass surgery and the extent of angiographically visible collateral vessels. Probst et al. (12) demonstrated similar results in conscious human subjects.

Myocardial flow distal to coronary stenosis has been shown (20) to be directly related to perfusion pressure, when maximal autoregulatory dilation has been achieved, as might be expected in patients with vessel occlusion superimposed on a tight stenosis. The higher myocardial perfusion pressure in patients of Group A is likely a result of the higher coronary occlusion pressure in the presence of collateral vessels. This higher myocardial perfusion pressure may limit myocardial ischemia during coronary occlusion.

Limitations of this study. Several limitations of this study should be considered: 1) Only eight of our patients had angiographically visible collateral vessels. Because of the small number of patients we did not further classify them according to the extent of collateral vessels. 2) There are several reports that transient collateral vessels become visible during coronary occlusion in patients undergoing coronary angioplasty (11,14) and during coronary spasm (21,22) and are transient. In this study, angiographic assessment of the presence or absence of collateral vessels was made before angioplasty, when the left anterior descending coronary artery was stenosed but not occluded. Because contralateral coronary arteriography was not performed during acute left anterior descending coronary artery occlusion, no conclusion can be made on the effects of transient collateral vessels. 3) For ethical reasons, the measurements were performed during continuous intravenous infusion of nitroglycerin to prevent spasm. This intervention may have influenced the collateral vessels (23,24). However, the dose was kept constant during the procedure in all patients and the total dose at the time of measurements was not significantly different between Group A and Group B; therefore, the measurements should be comparable. 4) Measurement of coronary occlusion pressure can be a problem during coronary angioplasty because the location of the balloon catheter across the stenotic lesion may influence the pressure measurement (12) and the pressure may be distorted because of overdamping, which is the result of minor air bubbles within the pressure transmitting system that includes the long and narrow lumen of the angioplasty catheter (25). However, because the same catheter system was used in every case and special attention was paid to eliminate the small bubbles, these errors should have influenced different patient groups to a similar extent.

Clinical implications. Recent observations indicate that increasing the duration of an individual inflation not only improves the immediate results of coronary angioplasty but also decreases the risk of restenosis (26). Therefore, we can prolong the duration of balloon inflation to obtain efficient coronary angioplasty in patients with collateral vessels be-
cause they show less myocardial ischemia during the balloon inflation.

The impact of collateral vessels during acute myocardial infarction has been assessed. Several previous studies (27,28) suggested that the presence of collateral vessels in the early hours of acute myocardial infarction was associated with a relatively smaller infarct. Our observations that collateral vessels have a protective effect during coronary occlusion support these reports, although the impact after several hours remains to be determined.

References

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