Coronary wedge pressure in relation to spontaneously visible and recruitable collaterals

BERNHARD MEIER, M.D., PHILIPP LUETHY, M.D., LEO FINCI, M.D., GIUSEPPE D. STEFFENINO, M.D., AND WILHELM RUTISHAUSER, M.D.

ABSTRACT Coronary angiography demonstrates only collateral arteries that are already in use (spontaneously visible collaterals). Percutaneous transluminal coronary angioplasty (PTCA) provides an opportunity to uncover collaterals ready to become functional in case of occlusion of the recipient artery (recruitable collaterals). The incidence of recruitable collaterals and their relation to the distal pressure in the occluded artery (coronary wedge pressure) during a 30 sec or longer balloon occlusion was assessed in 57 coronary arteries of 49 patients undergoing PTCA for a proximal coronary stenosis or occlusion. Collaterals to 75% of the arteries were present. Spontaneously visible collaterals were four times as frequent as recruitable collaterals. Coronary wedge pressure was significantly higher in arteries with spontaneously visible and recruitable collaterals (41 ± 12 and 36 ± 12 mm Hg, respectively) than in arteries without collaterals (18 ± 4 mm Hg). A coronary wedge pressure of 30 mm Hg or higher was found exclusively in the presence of collaterals. Electrocardiographic changes during balloon occlusion were found more frequently with arteries without collaterals than with arteries with spontaneously visible or recruitable collaterals. Chest pain was more frequent in patients without collaterals or with recruitable collaterals than in those with spontaneously visible collaterals. Major in-hospital events occurred in three patients with collaterals, with a salutary influence of the collaterals in two. The coronary wedge pressure allows prediction of recruitable collaterals. Their clinical impact remains to be investigated in long-term studies on large patient populations.


COLLATERAL CORONARY ARTERIES are important in coronary artery disease. A totally obstructed coronary artery perfused by well-developed collaterals has been shown to be hemodynamically comparable to an artery with a 91% to 99% diameter stenosis. Typically, it causes exertional angina pectoris but no pain at rest.

Collaterals are visible on a diagnostic coronary angiogram only if the recipient vessel is subtotally stenosed or occluded. Collaterals on standby can be rendered visible during coronary spasm or by a temporary occlusion of the recipient artery and simultaneous injection of contrast medium into the other arteries. We have termed such collaterals "recruitable."

The purpose of this study was to investigate in the context of percutaneous transluminal coronary angioplasty (PTCA) whether the distal coronary pressure measured during balloon occlusion (coronary wedge pressure) correlates with the presence of collaterals spontaneously visible on a routine coronary angiogram and with that of recruitable collaterals.

Methods

Definitions. The coronary wedge pressure was defined as the mean distal coronary pressure measured through the central lumen of a balloon catheter during a complete occlusion of the artery for at least 30 sec. It was rounded to the next value divisible by five. The transocclusional pressure gradient was defined as the difference between the mean aortic pressure measured through the guiding catheter at the coronary orifice and the simultaneous coronary wedge pressure. The transstenotic pressure gradient was defined as the difference between the mean pressure distal to the lesion (measured at the tip of the empty balloon catheter situated in the lesion) and the simultaneous mean pressure in the coronary ostium. The degree of stenosis was indicated as a visual estimate of diameter reduction.

Only collaterals filling at least a segment of the recipient vessel distal to the lesion were considered. Spontaneously visible collaterals were defined as collaterals documented by routine coronary angiography (performed after sublingual or during intravenous nitroglycerin administration). Recruiable collaterals were defined as collaterals not visible on the routine angiogram but visible during proximal balloon occlusion of the recipient coronary artery. Ipsilateral collaterals connect two vessels with a common coronary ostium, e.g., the left anterior descending coronary artery with the circumflex coronary artery or the right ventricular branch with the posterior descending
branch of the right coronary artery. Contralateral collaterals connect two coronary arteries with separate ostia, e.g., the left anterior descending coronary artery with the right coronary artery or the left circumflex coronary artery with the right coronary artery.

All angiographic assessments were done independently by two angiographers to determine the interobserver agreement. The observers were unaware of the values of the coronary wedge pressure. One of them assessed the angiograms a second time more than 9 months later without consulting the results of the first assessment to determine the intraobserver agreement.

Results

Patients. During the study period, patients were included consecutively if they had a complete proximal coronary occlusion as indication for PTCA and the balloon catheter could be advanced across the lesion, or if they had a proximal coronary stenosis with spontaneously visible collaterals or consented to a bifemoral arterial puncture necessary to assess the presence or absence of recruitable collaterals. Measurements were completed in all patients included.

In 51 PTCA procedures on 49 patients (42 men and seven women), 55 coronary arteries were examined during elective PTCA (47 arteries) or emergency PTCA (eight arteries). Two arteries were assessed twice, i.e., during initial and repeat PTCA, thus a total of 57 investigations were available for evaluation. Thirty left anterior descending coronary arteries (53%), 21 right coronary arteries (37%), and six left circumflex coronary arteries (10%) were investigated. The mean age of the patients was 53 ± 9 years (range 25 to 77). The mean duration of chest pain was 4.7 months and the mean New York Heart Association functional class for angina was 2.8. Infarction of the myocardial region of interest of 30 vessels (53%) was evident from ventriculography. In eight of them it was an acute infarction, representing the indication for emergency PTCA.

Technique. All patients were sedated with 15 mg of oral diazepam 2 hr before PTCA or with 5 to 10 mg of intravenous diazepam at the beginning of the intervention. Acetylsalicylic acid was started per os (100 mg) the day before or given intravenously (500 mg) at the beginning of the intervention. The patients were given a bolus of 10,000 U of heparin and low-molecular dextran was administered intravenously throughout the procedure. The patients received 0.2 mg of isosorbide dinitrate and 0.1 mg of nifedipine by the intracoronary route less than 30 min before the measurements. PTCA was performed by the femoral approach with No. 8F or 9F guiding catheters and Gruentzig balloon catheters (Schneider Shiley, Zürich, Switzerland) with a minimal luminal diameter of 0.39 to 0.51 mm (0.015 to 0.020 inch). They were equipped with steerable guidewires with diameters of 0.30 to 0.36 mm (0.012 to 0.014 inch).

During the first or second balloon filling, the pressure in the balloon was maintained at 2 bar for at least 30 sec and the following variables were assessed near the end of this period:

(1) The coronary wedge pressure was measured via the liquid column (nonionic contrast medium) in the central lumen of the balloon catheter by means of a Statham pressure transducer calibrated against a mercury pressure gauge with zero reference at ⅓ of the chest diameter above the table.

(2) The transocclusional pressure gradient was assessed by subtracting the coronary wedge pressure from the simultaneously recorded mean aortic pressure measured through the guiding catheter positioned in the coronary ostium. Again, the column of contrast medium and a Statham transducer (equicalibrated with the first one) were used for pressure transmission.

(3) Three to four electrocardiographic leads were recorded together with the pressures on a multichannel recorder. For the left anterior descending coronary artery leads I, II and V5 were monitored, and for the left circumflex and the right coronary arteries, leads, I, II, and III were recorded. The intracoronary electrocardiogram was recorded in four arteries (three left anterior descending coronary arteries and one circumflex coronary artery).

(4) The patient was interrogated about chest pain.

(5) An ipsilateral contrast injection was performed through the guiding catheter to ascertain the completeness of the balloon occlusion and to visualize recruitable ipsilateral collaterals. A 5 ml glass syringe delivering approximately 2 ml/sec was used.

(6) A contralateral contrast injection was performed through a No. 8F diagnostic catheter introduced through the opposite femoral artery to visualize recruitable contralateral collaterals. A 10 ml glass syringe was used. This injection was omitted if the attempted lesion was a total occlusion (n = 6), if spontaneously visible contralateral collaterals were present (n = 17), or if both applied (n = 15).

In five additional patients with elective PTCA and no previous myocardial infarction, the coronary wedge pressure was assessed at 15 and 60 sec of coronary occlusion during three or four consecutive balloon inflations and compared with the left ventricular end-diastolic pressure measured simultaneously with a high-fidelity manometer-tipped catheter introduced via the opposite femoral artery. These values were not rounded.

Results

Collaterals. Collaterals were present to 43 of the 57 arteries investigated (75%). In the subgroup of 17 left anterior descending coronary arteries not associated with myocardial infarction, collaterals were present to 13 (76%). Spontaneously visible collaterals were four times as frequent as recruitable collaterals in the total group (figure 1) and twice as frequent in the subgroup.

The interobserver and intraobserver agreements on angiographic presence or absence of collaterals were 95% and 91%, respectively. The instances of disagreement concerned six coronary arteries. They were reviewed and found to be borderline cases with opacification via collaterals of a minute segment of the recipient artery. This had been missed in one of three readings in four cases and in two of three readings in each of the others.
two cases. They were included in the group with collaterals. Their mean coronary wedge pressure was 22 mm Hg.

Among the 43 arteries with collaterals, 20 (47%) had contralateral collaterals only, six (14%) had ipsilateral collaterals only, and 17 (39%) had both. There was no significant difference in the presence of collaterals to arteries not associated with infarction (20/27 or 74%), to arteries associated with an acute infarction (5/8 or 63%), and to arteries associated with a remote infarction (18/22 or 82%).

Table 1 summarizes the baseline characteristics of patients and arteries associated with spontaneously visible, recruitable, or absent collaterals. They showed no significant differences.

**Coronary wedge pressure.** The coronary wedge pressures in the arteries with and without collaterals are depicted in figure 2. The mean value for arteries with collaterals was 40 ± 12 mm Hg (spontaneously visible collaterals 41 ± 12 mm Hg, recruitable collaterals 36 ± 12 mm Hg) and that for arteries without collaterals was 18 ± 4 mm Hg. The mean coronary wedge pressure of arteries without collaterals was significantly lower than that of arteries with collaterals (spontaneously visible or recruitable). There was no significant difference between the mean coronary wedge pressures of arteries with spontaneously visible or recruitable collaterals.

The coronary wedge pressures of the subgroup of 17 left anterior descending coronary arteries not associated with a myocardial infarction showed the same pattern. Coronary wedge pressure was 42 ± 10 mm Hg with collaterals (n = 13), i.e., 43 ± 11 mm Hg with spontaneously visible (n = 9) and 39 ± 10 mm Hg with recruitable collaterals (n = 4) (not significant). It was 20 ± 4 mm Hg without collaterals (p < .05 versus all groups with collaterals).

A coronary wedge pressure of 30 mm Hg or higher was found exclusively in arteries with collaterals. Two of the eight patients with PTCA for acute infarction had a coronary wedge pressure of at least 30 mm Hg. Both were already free of chest pain at the time of measurement and showed collaterals.

The reproducibility of the coronary wedge pressure measurements was documented by a mean variation of 8 ± 6% (range 2% to 24%) of 36 repeated measurements in five patients. It compared favorably to the reproducibility of the left ventricular end-diastolic pressures assessed simultaneously with a tip-manometer (mean variation 11 ± 7%, range 5% to 29%). Half of these repeat measurements were done at 15 and half at 60 sec of coronary occlusion. The mean coronary wedge pressure was 33 ± 8 mm Hg (range 16 to 42) at 15 sec and 32 ± 9 mm Hg (range 14 to 42) at 60 sec. The respective values for the left ventricular end-diastolic pressure were 17 ± 7 mm Hg (range 6 to 30) and 23 ± 11 mm Hg (range 6 to 40). The mean coronary wedge pressure at the end of the first 60 sec occlusion was 31 ± 10 mm Hg (range 14 to 38). It was equal to that at the end of the fourth 60 sec occlusion (31 ± 11 mm Hg, range 16 to 42). In seven of 36 measurements, the coronary wedge pressure was lower than the simultaneous left ventricular end-diastolic pressure.

**Transocclusional pressure gradient.** The transocclusional pressure gradient inversely reflects the coronary wedge pressure corrected for the mean systemic blood pressure. The values of the different groups were 53 ± 15 mm Hg (range 25 to 100) for arteries with collaterals (54 ± 16 mm Hg, range 25 to 100) for arteries with

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**TABLE 1**

**Characteristics associated with spontaneously visible, recruitable, and absent collaterals**

<table>
<thead>
<tr>
<th></th>
<th>Spontaneously visible</th>
<th>Recruitable</th>
<th>Absent</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of arteries</td>
<td>35</td>
<td>8</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Coronary wedge pressure</td>
<td>41 ± 12</td>
<td>36 ± 12</td>
<td>18 ± 4</td>
<td></td>
</tr>
<tr>
<td>mm Hg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (yr)</td>
<td>52 ± 9</td>
<td>60 ± 11</td>
<td>52 ± 9</td>
<td>NS</td>
</tr>
<tr>
<td>Female sex (%)</td>
<td>20</td>
<td>13</td>
<td>0</td>
<td>NS</td>
</tr>
<tr>
<td>Duration of symptoms (mo)</td>
<td>5 ± 7</td>
<td>3 ± 2</td>
<td>4 ± 2</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA functional angina class</td>
<td>2.8 ± 0.9</td>
<td>3.1 ± 0.7</td>
<td>2.7 ± 1.0</td>
<td>NS</td>
</tr>
<tr>
<td>Acute infarction (%)</td>
<td>14</td>
<td>0</td>
<td>21</td>
<td>NS</td>
</tr>
<tr>
<td>Remote infarction (%)</td>
<td>49</td>
<td>13</td>
<td>29</td>
<td>NS</td>
</tr>
<tr>
<td>LAD (%)</td>
<td>54</td>
<td>50</td>
<td>50</td>
<td>NS</td>
</tr>
<tr>
<td>RCA (%)</td>
<td>37</td>
<td>37</td>
<td>36</td>
<td>NS</td>
</tr>
<tr>
<td>LCx (%)</td>
<td>9</td>
<td>13</td>
<td>14</td>
<td>NS</td>
</tr>
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</table>

LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; RCA = right coronary artery.
spontaneously visible collaterals; 49 ± 8 mm Hg, range 35 to 60 for arteries with recruitable collaterals) and 75 ± 11 mm Hg (range 55 to 95) for arteries without collaterals. The mean value of arteries with spontaneously visible or recruitable collaterals were similar but each of them was significantly lower than the mean value of arteries without collaterals. A trans-occlusional pressure gradient of 50 mm Hg or less was found exclusively in arteries with collaterals.

Transstenotic pressure gradient. The transstenotic pressure gradient was measured in 54 arteries. In arteries with collaterals (n = 41), the mean transstenotic pressure gradient was 47 ± 14 mm Hg (range 20 to 100). It was 48 ± 15 mm Hg (range 20 to 100) in arteries with spontaneously visible collaterals (n = 33) and 44 ± 13 mm Hg (range 30 to 60) in arteries with recruitable collaterals (n = 8). The mean transstenotic pressure gradient in arteries without collaterals (n = 13) was 57 ± 20 mm Hg (range 5 to 85). None of the differences were statistically significant.

Degree of stenosis. The mean degree of stenosis was significantly higher in arteries with collaterals (93 ± 8%, range 60% to 100%) than in arteries without collaterals (82 ± 16%, range 40% to 100%) (p < .005). In the group with collaterals, 40% of the lesions (17/43) were total occlusions compared with 21% (3/14) in the group without collaterals (not significant). The subgroup with spontaneously visible collaterals had a mean degree of stenosis of 95 ± 6% (range 80% to 100%), significantly higher (p < .001) than that of the subgroup with recruitable collaterals (83 ± 10%, range 80% to 90%), which was quite similar to that of the group without collaterals.

Electrocardiographic changes. Electrocardiographic alterations indicating ischemia, such as ST segment elevation, ST segment depression, or T wave changes, occurred in 24 of 57 arteries (42%) during 30 sec of balloon occlusion. Figure 3 shows the incidence of electrocardiographic changes in the different groups and subgroups. The mean coronary wedge pressure was 26 ± 14 mm Hg (range 10 to 60) in arteries with electrocardiographic changes and 41 ± 11 mm Hg
(range 10 to 60) in arteries without such changes (p < .001).

Chest pain. Chest pain occurred during 30 sec of balloon occlusion of 27 of 57 arteries (47%). Figure 4 shows the incidence of chest pain in the different groups and subgroups. The mean coronary wedge pressure was 29 ± 16 mm Hg (range 10 to 60) in arteries producing chest pain and 39 ± 12 mm Hg (range 10 to 55) in arteries not producing chest pain (p < .001).

Results of PTCA. Of the 51 PTCA procedures, 47 (92%) were considered successful in terms of improvement of the stenosis, reduction of the transstenotic pressure gradient, and absence of major complications during the hospital stay. There were four failures. The first failure was an unsuccessful attempt to pass the body of the balloon through a chronic total occlusion of the left anterior descending coronary artery of a 53-year-old man. The tip of the balloon catheter could be advanced into the distal segment of the artery for pressure measurement. The patient had spontaneously visible collaterals, a coronary wedge pressure of 50 mm Hg, and a transocclusional pressure gradient of 40 mm Hg, and a normal function of the left ventricle. The patient continued to experience exertional chest pain and underwent elective coronary artery bypass surgery 2 months later.

The second failure occurred in a 36-year-old man with a 90% stenosis of the right coronary artery that turned into an occlusion during PTCA due to a dissection. The patient had spontaneously visible collaterals, a coronary wedge pressure of 45 mm Hg, and a transocclusional pressure gradient of 45 mm Hg. He had slight, nonsustained chest pain and no enzymatic or electrocardiographic evidence for myocardial infarction. He underwent elective coronary artery bypass surgery 2 days later.

The third failure concerned a 59-year-old man with an initially successful PTCA of a dominant right coronary artery. Spontaneously visible collaterals were present, the coronary wedge pressure was 50 mm Hg, and the transocclusional pressure gradient was 45 mm Hg. He suffered an acute vessel occlusion the night after the intervention, accompanied by slight pain and an elevation of the creatine kinase level to 1.3 times normal. There were no new Q waves on the electrocardiogram. Exertional angina persisted and a control angiogram 9 months later revealed a partially recanalized and collateralized right coronary artery with a new small inferior hypokinesia.

The fourth failure occurred in a 48-year-old man who underwent emergency double-vessel PTCA combined with thrombolysis (intracoronary streptokinase) for an acute anterior infarction. He had a totally obstructed left anterior descending coronary artery and a significantly stenosed left circumflex coronary artery. The procedure was successful in both arteries and the patient remained free of chest pain but died suddenly after 5 days while he was still in the hospital. He had spontaneously visible collaterals to the left anterior descending coronary artery, a coronary wedge pressure of 40 mm Hg, and a transocclusional pressure gradient of 45 mm Hg. There were no collaterals to the circumflex coronary artery and its coronary wedge pressure was not assessed. Necropsy was refused by the patient’s family.

Discussion

The coronary wedge pressure can be measured during PTCA without additional material or maneuvers provided the dilatation equipment selected allows reliable distal pressure measurements. The pressure values were well reproducible when measured during successive vessel occlusions in our study and in a previous report. The transstenotic pressure gradient mea-

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**FIGURE 4.** Chest pain during a 30 sec balloon occlusion of a coronary artery. Chest pain occurred significantly more frequently in patients without collaterals than in those with collaterals (panel A). The subgroup of patients with recruitable collaterals, however, showed an incidence of chest pain significantly different from that of the subgroup with spontaneously visible collaterals and similar to that of the group without collaterals (panel B).
PATHOPHYSIOLOGY AND NATURAL HISTORY—CORONARY ANGIOPLASTY

![Diagram of ECG leads and pressures](image)

FIGURE 5. Coronary wedge pressure and left ventricular end-diastolic pressure during balloon occlusion of the left anterior descending coronary artery of a 69-year-old man. Three standard leads and the intracoronary (ic) electrocardiographic lead, a phonocardiogram (Phono), the left ventricular pressure (LVP) measured with a high-fidelity tip-manometer and in the right hand panel simultaneously with a hydraulic pressure transducer, its derivative (dp/dt), the mean aortic pressure (AP), and the mean coronary artery pressure are depicted before the stenosis is crossed (baseline) and at 15 and 60 sec of balloon occlusion. The coronary wedge pressure (CWP) remains stable at 20 mm Hg while the left ventricular end-diastolic pressure increases from 28 (15 sec occlusion) to 31 mm Hg (60 sec occlusion) with a marked a-wave (a) and an apparent fourth heart sound (IV). The patient had no chest pain at 15 sec of occlusion (mild ischemic electrocardiographic changes) but he had chest pain at 60 sec of occlusion (marked ischemic electrocardiographic changes, e.g., 0.6 mV ST segment elevation in the intracoronary lead). There were no spontaneously visible or recruitable collaterals.

measured during PTCA may be overestimated because of the aggravation of the stenosis by the presence of the balloon. However, this reservation does not apply to the assessment of the coronary wedge pressure, which requires complete occlusion of the artery.

A possible interference has to be kept in mind between the pressure used to fill the balloon (inflation pressure) and the pressure transmitted from the balloon tip. The material used in this study is made of fairly stiff polyvinyl chloride and features two semilunar lumina in the balloon shaft. Stepwise assessment of the coronary wedge pressure in four patients at inflation pressures increasing from 1 to 10 bar revealed no measurable changes and confirmed unbiased transmission of the coronary pressure during balloon fillings at a wide pressure range. Coronary wedge pressures used for analysis were assessed uniformly at balloon pressures of 2 bar.

There was no difference in coronary wedge pressures assessed at the beginning and at the end of a 60 sec inflation cycle, whereas the simultaneously measured left ventricular end-diastolic pressure increased (figure 5). We found no trend in the coronary wedge pressure measured during the first compared with that measured during the last of a series of successive inflation cycles. Likewise, the appearance of recruitable collaterals was constant during successive balloon occlusions in another study. We performed the assessments of pressures used for further analysis and the contrast injections during the first or second balloon filling in all cases.

Low coronary wedge pressures reflect capillary resistance, right atrial filling pressure, and left ventricular wall tension. We found no apparent relation to the left ventricular end-diastolic pressure. From an animal study, it was concluded that from 20 mm Hg upward coronary wedge pressure reflects collateral flow. Our data indicate that a coronary wedge pressure of 30 mm Hg or higher measured during a proximal occlusion of at least 30 sec predicts spontaneously visible or immediately recruitable collaterals (table 2). The only alternative method to document the presence or absence of recruitable collaterals consists of an injection of contrast medium into the potential donor arteries during proximal occlusion of the recipient vessel. This requires simultaneous bilateral coronary catheterization.

A major limitation of our model is the administration of vasodilators to all patients before the measurements. They are likely to alter antegrade and collateral coronary perfusion. However, the same alterations may prevail in patients on a regular, long-term regimen of these drugs.

Depending on the chronicity and severity of coronary artery disease and the severity of the stenoses of patients accepted for PTCA, spontaneously visible collaterals are found in 19% to 61% (our data). The incidence of spontaneously visible collaterals was high in this study population because their presence was one of the selection criteria. In an unselected group of 100

<table>
<thead>
<tr>
<th>TABLE 2</th>
<th>Coronary wedge pressure ≥30 mm Hg as indicator for collaterals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity</td>
<td>86% (37/43)</td>
</tr>
<tr>
<td>Specificity</td>
<td>100% (14/14)</td>
</tr>
<tr>
<td>Predictive value</td>
<td>100% (37/37)</td>
</tr>
</tbody>
</table>
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consecutive patients undergoing PTCA during the same period. Spontaneously visible collaterals were present in 37%. The question whether collaterals can be recruited rapidly in the event of an acute vessel occlusion has been addressed repeatedly in animal preparations and human studies. In a study of 24 dogs,11 16 developed collaterals during 4 min of acute coronary artery occlusion. At 0.5 and 4 min of occlusion, they had a mean coronary wedge pressure of 42 and 49 mm Hg, respectively, compared with 20 and 24 mm Hg in the eight dogs without collaterals. These figures are in keeping with our measurements. They indicate that if collaterals develop during the first minutes of an acute coronary artery occlusion, they open within the first 30 sec and improve only insignificantly up to 4 min. It is unclear at what time further collaterals develop and whether they are still capable of limiting myocardial damage.

A recent report indicates that jeopardized collaterals, i.e., collaterals from a diseased donor vessel, are less efficient than collaterals from a healthy vessel.12 The coronary wedge pressure automatically accounts for the degree of jeopardy of collaterals, which may be difficult to estimate from an angiogram. In our study, three of the principal potential donor vessels were afflicted by significant stenoses. None provided collaterals and the coronary wedge pressure was 20 mm Hg or less in all three arteries dependent on these vessels.

The transocclusional pressure gradient is derived directly from the coronary wedge pressure. It provides little additional information but it is corrected for the systemic blood pressure and may be useful in case of marked systemic hypotension or hypertension at the moment of assessment of the coronary wedge pressure. The highest transocclusional pressure gradient measured in a patient with collaterals amounted to 100 mm Hg. The patient was hypertensive with a mean aortic pressure of 140 mm Hg.

The transstenotic pressure gradient allows no inferences on the presence or absence of collaterals. A high transstenotic pressure gradient may well be an incentive for the development of collaterals. In parallel to their development, however, the transstenotic pressure gradient decreases.

The degree of stenosis was higher in arteries with spontaneously visible collaterals than in those with recruitable or without collaterals. This indicates again that collaterals are visible only if the stenosis of the recipient vessel approaches or reaches 100%.3 The nonquantitative assessment of stenosis used in this study precludes further analysis of this particular variable.

The next best indicator of collaterals after the coronary wedge pressure and the degree of stenosis is the electrocardiogram. Ischemic changes were seen significantly more often in patients without collaterals (figures 3 and 5). The intracoronary electrocardiogram shows a particularly good correlation with the presence or absence of collaterals.7

Chest pain was less frequently reported in patients with spontaneously visible collaterals than in those with recruitable or without collaterals (figure 4). This finding may suggest that the pain threshold is different in patients not yet used to the relatively low distal coronary pressure provided by collaterals. However, pain during an intervention is highly subjective and unreliable and was found to have no significant relation to the presence of collaterals in another study.5

Our data revealed no cut-off value of the coronary wedge pressure for presence or absence of electrocardiographic changes or chest pain. This may be due to the heterogeneity of the study population. Yet there was a cut-off value of 30 mm Hg or higher for prediction of collaterals in the heterogenous total cohort comprising patients with acute and remote infarctions as well as in a more homogeneous subgroup of patients with proximal left anterior descending coronary artery stenosis unassociated with infarction. It complies well with coronary wedge pressures measured in arteries with or without collaterals in other studies.13-15 One study failed to find a difference in the coronary wedge pressures of arteries with or without collaterals.16 This may be attributed partially to the fact that patients with recruitable collaterals were not identified and included with those without collaterals.

As for the clinical implications of collaterals, previous studies have emphasized their importance in the event of coronary artery occlusion because they may preserve left ventricular function.12, 17-19 Left ventriculograms obtained during brief balloon occlusion of a major coronary artery showed a lower percentage of ventricular perimeter with new hypocontractility if collaterals were present.20 Other studies contest a beneficial influence of collaterals in single-vessel disease21 or limit it to disease involving the left anterior descending coronary artery.22 This may be because of the benign course of single-vessel coronary disease whether it is treated medically or by PTCA. In our study, there was no significant difference either in the presence of collaterals or in the coronary wedge pressure between arteries that were associated with an acute, an old, or no myocardial infarction. Yet the assessment was made 3 hr or more after the onset of infarction. The highest coronary wedge pressure in patients with an
acute infarction and persistent chest pain at the time of measurement was 25 mm Hg. A protective effect of spontaneously visible collaterals was apparent in two patients with acute vessel occlusion secondary to PTCA. Moreover, follow-up angiography in three patients with spontaneously visible collaterals and coronary wedge pressures of 40 to 60 mm Hg on their successful PTCA showed complete occlusion of the coronary artery in question, but none of the patients had sustained a myocardial infarction. An argument in favor of the potential salutary power of recruitable collaterals is the finding that patients without electrocardiographic changes or chest pain during 30 sec of balloon occlusion had a higher mean coronary wedge pressure than patients with these signs of myocardial ischemia.

The coronary wedge pressure provides a simple means to gain information about the collateralization of a coronary artery subjected to PTCA. It reflects not only spontaneously visible collaterals but also recruitable collaterals not evident from diagnostic angiograms. The higher the coronary wedge pressure, the more assured the operator can be that in case of acute vessel occlusion adequate perfusion of the jeopardized myocardium will be maintained. The clinical benefit of a high coronary wedge pressure or recruitable collaterals remains to be assessed in long-term studies on large patient populations. It cannot be derived from the anecdotal evidence supplied in this study, which was limited by the great variety of patients included.

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