Potential Protective Effect of High Coronary Wedge Pressure on Left Ventricular Function After Coronary Occlusion

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To assess the potential of coronary collateral circulation to protect myocardium after occlusion of a coronary vessel, the mean coronary wedge pressure, the angiographic grade of collateral channels, and the left ventricular function were studied in 47 consecutive patients with mechanical recanalization of totally occluded coronary arteries. Coronary wedge pressure measurements were obtained 39 ± 51 days (range, 2 hours to 361 days) after the presumed time of occlusion. The patients were divided into two groups: 31 with a coronary wedge pressure more than 30 mm Hg (group 1) and 16 with a coronary wedge pressure of or less than 30 mm Hg (group 2). Patients in group 1 had a significantly higher mean global left ventricular ejection fraction than those in group 2 (63 ± 9% vs. 49 ± 7%, p < 0.001). Regional left ventricular function (artery-related area change) was also superior in group 1 compared with group 2 (47 ± 11% vs. 36 ± 10%, p < 0.01). Global left ventricular function was significantly correlated to coronary wedge pressure (r = 0.51, p < 0.001) but not to the angiographic presence of collaterals. The data suggest that a high coronary wedge pressure is associated with improved left ventricular function after coronary artery occlusion and that coronary wedge pressure more accurately reflects the physiological role of collaterals than their angiographic presence. (Circulation 1988; 78:566-572)

The functional importance of collateral coronary circulation in patients with coronary artery disease remains controversial. Collaterals are angiographically demonstrable only if severe coronary artery disease is present. Several investigators have failed to demonstrate a long-term beneficial effect of collaterals on left ventricular function. Other studies suggest that in patients with severe coronary artery stenoses or occluded coronary arteries, collaterals may have a protective role concerning myocardial function. However, most of the available clinical data originate from postmortem or angiographic studies.

Experimentally, the coronary collateral circulation has been studied mainly in the dog heart. Because collaterals are more developed in dogs than in healthy humans, the results cannot be extrapolated to the human coronary circulation. The hemodynamics of coronary collaterals have been studied directly in humans during aorto-coronary bypass surgery, and, more recently, the pressure distally to coronary lesions was measured during percutaneous angioplasty and the relation of the coronary wedge pressure (pressure in the distal part of the occluded artery) to spontaneously visible and recruitable collaterals has been established. To evaluate the protective role of the coronary collateral circulation, we studied the relation between the mean coronary wedge pressure measured during percutaneous transluminal coronary angioplasty and the left ventricular function in patients with occlusion of a major coronary vessel.

Patients and Methods

Patients

Coronary wedge pressure measurements were done in 53 of 108 consecutive patients with attempted recanalization of a total coronary occlusion. Four patients with a previous myocardial infarction in a region other than that supplied by the attempted vessel were excluded. Two additional patients were excluded because of unsatisfactory quality of the left ventriculogram. The remaining 47 patients constituted the study population. Among them, 13 patients underwent mechanical recanalization during the acute phase of a myocardial infarction. The remaining 34 underwent an elective procedure for a...
chronic total occlusion. The date of occlusion was supposed to be the moment of the acute infarction. In patients without clinically documented acute myocardial infarction, the most marked change in anginal symptoms was considered as the occlusion date. Thirty-seven patients had clinically documented myocardial infarction. In four additional patients, a clear moment of unstable angina was noted. In six patients, no such acute coronary event was found, and the date of occlusion remained undetermined. Twenty patients with normal coronary arteries and normal left ventricular function served as a control group for angiographic evaluation of the regional left ventricular function.

**Angiography and Angioplasty**

Percutaneous transluminal coronary angioplasty was done by the femoral approach as previously described. Steerable dilatation catheters (Schneider Shiley, Zurich, Switzerland) were used in all cases. The balloon sizes ranged from 2.5 to 3.4 mm, and their internal luminal diameters ranged from 0.39 to 0.55 mm.

The diagnostic angiograms were performed 11 ± 23 days (range, 1–140 days) before angioplasty for the patients with elective procedures (n = 34); eight patients had recanalization of the occluded artery simultaneously with the diagnostic angiogram, 20 within 7 days after the diagnostic angiogram, and six patients had delayed angioplasty at 10, 18, 29, 32, 54, or 140 days.

The extent of the collateral circulation on the initial angiogram was assessed by two independent observers according to the classification of Rentrop et al: 0, no visible filling of any collateral channels; 1+, collateral filling of branches of the occluded vessel without any dye reaching the epicardial segment of the occluded vessel; 2+, partial collateral filling of the epicardial segment of the occluded vessel; and 3+, complete collateral filling of the occluded vessel. All patients received either intravenous, intracoronary, or sublingual nitrates before angioplasty.

**Coronary Wedge Pressure**

Coronary wedge pressure was defined as the mean distal coronary pressure measured at the tip of the dilatation catheter while the balloon was inflated in the stenosis with a pressure of two bars. Correct position of the balloon was documented on cinefilm. The pressure was measured via the liquid column of nonionic contrast medium in the central lumen of the balloon catheter by a Statham P23G strain gauge (Statham Instruments, Oxnard, California) and recorded on a photographic recorder (Model DR 16, Electronics for Medicine, White Plains, New York). The mean pressure was rounded off to the next value divisible by 5 as soon as it had leveled off. This took from 15 to 30 seconds depending on the type of catheter used. Before each procedure, the pressure recording system was calibrated to zero level at three fifths of the anteroposterior chest diameter above the table at the level of the fourth intercostal space. A simultaneous tracing from guiding and dilatation catheters was obtained just before advancing the latter into the coronary tree. This allowed for checks for calibration and leaks in the pressure lines.

**Global and Regional Left Ventricular Function**

The global and regional left ventricular ejection fractions were evaluated from biplane ventriculo-

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**Figure 1.** Diagram defining the nine myocardial regions considered [i.e., five for the 30° right anterior oblique (RAO) projection and four for the 60° left anterior oblique (LAO) projection]. First, the respective centers of gravity (Gd, Gs) and midaortic points of the end-diastolic and end-systolic RAO silhouettes are determined to define the zero reference line of each silhouette. Then, radii originating from the center of gravity are drawn at 30°, 90°, 150°, 210°, 270°, and 300° from the zero reference line. These radii define the five labeled regions of the RAO silhouettes: anterobasal (1), anterolateral (2), apical (3), diaphragmatic (4), and posterobasal (5). The same is done for the LAO projection with the angles 60°, 120°, 180°, 240°, and 300°. This yields the four regions: posterobasal (6), posterolateral (7), distal septal (8), and proximal septal (9).
grams, performed before diagnostic coronary angiograms or immediately before angioplasty. Filming was performed at 50 frames/sec during a power injection of 40–48 ml nonionic contrast medium through a pigtail catheter over a period of 4 seconds. Left ventricular ejection fractions were determined from end-diastolic and end-systolic contours with the area-length method. Premature contractions and the two following cycles were excluded from analysis. Left ventricular wall segments were determined as described in Figure 1. Regional left ventricular function was assessed for each segment by computerized planimetry as follows: segmental area change (%) = (segmental end-diastolic area − segmental end-systolic area/segmental end-diastolic area) × 100. The following relation between the occluded arteries and the myocardial segment was assumed: for the left anterior descending coronary artery, the anterobasal, anterolateral, apical, distal septal, and proximal septal segments; for the right coronary artery, the diaphragmatic, posterobasal, and posterolateral segment; and for the left circumflex coronary artery, the posterior, posterolateral, and posterobasal segments.

**Statistics**

All values are reported as mean ± SD. Differences in the distribution of age, sex, occluded vessel, and number of diseased vessels between groups were evaluated by \( \chi^2 \) technique. An unpaired \( t \) test was used to evaluate continuous variables such as coronary wedge pressure, left ventricular ejection fraction, left ventricular end-diastolic pressure, artery-related area changes, delay between occlusion and angiography, delay between occlusion and coronary wedge pressure measurements, and duration of anginal symptoms. The correlation between coronary wedge pressure and left ventricular ejection fraction was evaluated

### TABLE 1. Clinical and Angiographic Characteristics of 47 Patients

<table>
<thead>
<tr>
<th></th>
<th>CWP &gt;30 mm Hg (n = 31)</th>
<th>CWP ≤30 mm Hg (n = 16)</th>
<th>( p )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>56 ± 8</td>
<td>52 ± 10</td>
<td>NS</td>
</tr>
<tr>
<td>Man:woman ratio</td>
<td>29:2</td>
<td>14:2</td>
<td>NS</td>
</tr>
<tr>
<td>Number of diseased vessels</td>
<td>1</td>
<td>25 (81%)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5 (16%)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1 (3%)</td>
<td>NS</td>
</tr>
<tr>
<td>Occluded vessels</td>
<td>LAD</td>
<td>17 (55%)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>RCA</td>
<td>7 (23%)</td>
<td>NS</td>
</tr>
<tr>
<td></td>
<td>LCx</td>
<td>7 (23%)</td>
<td>NS</td>
</tr>
<tr>
<td>Time since occlusion (days)*</td>
<td>36 ± 2</td>
<td>45 ± 90</td>
<td>NS</td>
</tr>
<tr>
<td>Time from onset of symptoms to occlusion (weeks)*</td>
<td>13 ± 11</td>
<td>5 ± 8</td>
<td>&lt;0.05</td>
</tr>
</tbody>
</table>

*Available in 41 of 47 patients. CWP, coronary wedge pressure; LAD, left anterior descending coronary artery; RCA, right coronary artery; LCx, left circumflex coronary artery; NS, not significant.

**FIGURE 2.** Bar charts of mean global left ventricular ejection fraction for high (>30 mm Hg) and low (≤30 mm Hg) coronary wedge pressure (CWP). LAD, left anterior descending coronary artery; LCx, left circumflex coronary artery; RCA, right coronary artery; NS, not significant.

**FIGURE 3.** Plot of relation between global left ventricular ejection fraction and coronary wedge pressure.
by a least-squares regression. Significance was accepted at the 5% probability level.

**Results**

The patients were separated into two groups according to the level of coronary wedge pressure: group 1 consisted of 31 patients with a coronary wedge pressure in the occluded artery more than 30 mm Hg (range, 35–65 mm Hg; mean, 45 ± 9 mm Hg) and group 2 consisted of 16 patients whose coronary wedge pressure in the occluded artery was 30 mm Hg or less (range, 10–30 mm Hg; mean, 23 ± 7 mm Hg). The cutoff was done according to previously published data.22 The baseline characteristics of the two groups are summarized in Table 1. There was a similar distribution of sex, extent of coronary artery disease, vessel distribution, and interval between baseline ventriculography and measurement of the coronary wedge pressure. The percentage of patients with acute myocardial infarction was smaller in group 1 (23%, or seven of 31) than in group 2 (43%, or seven of 16), but the difference was not statistically significant. Left ventricular end-diastolic pressure was lower in group 1 (12 ± 5 vs. 15 ± 5 mm Hg in group 2). Again, the difference was not statistically significant. The duration of anginal symptoms until the presumed date of occlusion was significantly longer in group 1 (13 ± 11 weeks) than in group 2 (5 ± 8 weeks) (p<0.05).

**Global Left Ventricular Function**

Figure 2 shows that the mean value of the global left ventricular ejection fraction was significantly higher in group 1 (63 ± 9%) than in group 2 (49 ± 7%) (p<0.001). This difference remained significant when only the 34 patients with elective procedures were

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**Figure 4.** Plot of relation between coronary wedge pressure and angiographic degree of collateralization. NS=not significant.

**Figure 5.** Plot of global left ventricular ejection fraction for different angiographic degrees of collateralization. NS, not significant.

**Figure 6.** Bar charts of occluded artery related regional left ventricular function for high (>30 mm Hg) and low (≤30 mm Hg) coronary wedge pressure and for normal controls. LAD, left anterior descending coronary artery; RCA, right coronary artery; LCX, left circumflex coronary artery; CWP, coronary wedge pressure; NS, not significant.
considered (62 ± 10% vs. 48 ± 6%; p<0.005). The global left ventricular ejection fraction was also higher in group 1 than in group 2 when comparing patients stratified to the vessel occluded (Figure 2). This difference, however, was not significant in the subgroup with recanalization of the left circumflex coronary artery. This may be attributed to the small size of this group. There was a significant correlation between the coronary wedge pressure and the global left ventricular ejection fraction: \( r = 0.51, p = 0.001 \) (Figure 3). Furthermore, with a cutoff value of the coronary wedge pressure at 30 mm Hg, it was possible to separate the patients with a normal global left ventricular function (ejection fraction, \( \geq 55\% \)) from those with an impaired global left ventricular function. Although there was a relation between the coronary wedge pressure and the angiographically determined extent of collateral circulation (Figure 4), the latter did not significantly correlate with the global left ventricular ejection fraction (Figure 5).

Regional Ejection Fraction

Wall motion of the myocardial area related to the occluded artery was better preserved albeit not normal in group 1 with high compared with group 2 with low coronary wedge pressure (Figure 6). The difference remained significant with separate analyses of the left anterior descending coronary artery and the right coronary artery. The difference was not significant in the left circumflex group, probably because of the small number of patients.

Discussion

Despite anecdotal reports supporting the salutary potential of coronary collateral circulation,\textsuperscript{12,26,27} its beneficial effect on left ventricular function in patients with coronary heart disease has been questioned by several investigators.\textsuperscript{1,5}

Studies limited to occluded arteries support a positive correlation between the presence of coronary collaterals and preserved left ventricular function.\textsuperscript{12,16,22} Recently, Saito et al\textsuperscript{13} found that among patients with successful thrombolysis, those with good collaterals showed more improvement in left ventricular function (acute vs. late measurements) than those without. This improvement was not related to the delay between onset of symptoms and beginning of intracoronary lysis. In these patients, collaterals prevented complete infarction despite coronary occlusion during several hours. Two other studies emphasize the importance of residual flow attributed to subtotal occlusion or good collaterals in the first hours of acute myocardial infarction.\textsuperscript{14,15}

The conclusions of these studies were, in general, supported by angiographic evaluation of the extent of collaterals. Current angiographic equipment reveals only vessels with luminal diameters of at least 100 μm. Whether good angiographic visualization represents good flow in a given vessel remains an open issue. Angiography may not be the best method to demonstrate the protective effect of collaterals in patients.

Coronary Wedge Pressure

A more physiological approach was provided by hemodynamic evaluation of coronary collateral flow obtained in humans during aortocoronary bypass surgery.\textsuperscript{17} As previously validated in animal studies,\textsuperscript{28} coronary pressure distally to an occlusion has been considered to constitute an indicator of collateral function. More recently, four studies have reported the measurement of this pressure during percutaneous coronary angioplasty.\textsuperscript{18-22} Coronary wedge pressure was found to reflect fairly well the angiographically estimated degree of collateralization.\textsuperscript{22} We have shown that the coronary wedge pressure not only reflects already visible collaterals but also recruitable collaterals not visible on diagnostic angiograms.\textsuperscript{22} Furthermore, an increased restenosis rate was reported to be associated with both angiographically well-developed collateral\textsuperscript{21} and a high coronary wedge pressure.\textsuperscript{29}

In the present study, we have considered the distal coronary pressure determined during percutaneous balloon revascularization of totally occluded coronary arteries as a functional indicator of collateral circulation. When performing pressure recordings, the balloon catheter was not flushed with saline. The coronary wedge pressure was measured with a column of contrast medium resulting in a nonphasic (damped) pressure tracing corresponding to the mean distal pressure. Even investigators recording more phasic pressures were prompted to use only the mean pressure for comparison between the different groups because of important damping of high-frequency components by the fluid-filled systems and the small lumen of the catheters used.\textsuperscript{18,20}

Besides coronary flow, there may be other significant determinants of coronary wedge pressure. In previous studies,\textsuperscript{22} the coronary wedge pressure was assessed at 15 and 60 seconds of coronary occlusion during three consecutive balloon inflations and compared with the left ventricular end-diastolic pressure measured simultaneously with a high-fidelity manometer-tipped catheter introduced through the opposite femoral artery. There was no difference in coronary wedge pressure assessed at the beginning and at the end of a 60-second inflations cycle, whereas the left ventricular end-diastolic pressure increased. Moreover, in this series of patients, we found no difference in left ventricular end-diastolic pressure between groups 1 and 2, but these values were not obtained simultaneously with coronary wedge pressure measurements.

The results indicate that the higher the perfusion pressure provided by the collaterals, the better the systolic wall motion of the occluded artery related segment is preserved. Global left ventricular ejection fraction was found to be higher in patients with a high coronary wedge pressure than in those with a
low coronary wedge pressure. The difference between group 1 with high and group 2 with low coronary wedge pressure was more pronounced in patients with occlusion of the left anterior descending coronary artery than in patients with occlusion of the right coronary artery or the left circumflex coronary artery. The small number of patients with occlusion of the right coronary artery or the left circumflex coronary artery may at least partially explain the lesser extent of the positive effect of a high coronary wedge pressure. Furthermore, the left anterior descending distribution in our analysis evaluates five regions of interest versus three regions in the right and left circumflex coronary artery distribution, respectively.

Our data support the hypothesis that more than 30 mm Hg of coronary wedge pressure preserves some but not all contractile function in the myocardial area dependent on an occluded artery. In contrast, we found no significant correlation between left ventricular function and the angiographically determined degree of coronary collateral circulation. This leads us to conclude that coronary wedge pressure is a more accurate indicator of the protective role of coronary collaterals after coronary occlusion.

Limitations of Study

The major limitation of such a study is the delay between the occlusion of the vessel and the assessment of the coronary wedge pressure. It is probable that the perfusion pressure derived from collaterals in the first minutes and hours after occlusion is the most important determinant for myocardial protection during acute myocardial infarction. Because the collateral flow is likely to increase with time after coronary artery occlusion, it is probable that some patients allocated to the group with high coronary wedge pressure did indeed have a low coronary wedge pressure during the first hours of occlusion. This would only reinforce our conclusions.

All our patients were studied after administration of either intravenous or sublingual nitrates, which have been shown to reduce collateral resistance in the fibrillating heart. Their effect on collateral inflow in beating hearts as measured by the coronary wedge pressure has not been clarified.

Conclusion

Our data suggest a relation between angiographically determined coronary collaterals and coronary wedge pressure. The results indicate that a high coronary wedge pressure is associated with less-impaired left ventricular function after coronary artery occlusion. Coronary wedge pressure seems to be a better determinant of the protective role of the collaterals than does angiographic assessment.

References

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*Key Words* • coronary wedge pressure • collaterals • coronary occlusion • regional ventricular function
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