Time Course of Functional and Biochemical Recovery of Myocardium Salvaged by Reperfusion

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To characterize the functional and biochemical recovery of myocardium salvaged by reperfusion, 19 anesthetized mongrel dogs underwent 2 hour occlusion of the proximal left anterior descending coronary artery, followed by reperfusion for up to 2 weeks. Thirteen dogs had a permanent occlusion and served as the control group. All dogs had serial two-dimensional echocardiograms and in vivo biopsies for adenosine triphosphate (ATP) and creatine phosphate after occlusion and at the time of sacrifice (6 hours, n = 15; 7 days, n = 6; or 14 days after occlusion, n = 11). The area of necrosis and area at risk of necrosis were identified in dogs sacrificed at 6 hours.

After 4 hours of reperfusion, the area of necrosis determined by the triphenyltetrazolium chloride technique, expressed as a function of the area at risk by in vivo monastral blue injection, was 23.9 ± 5.8% (mean ± standard error of the mean) and largely subendocardial, compared with 89.1 ± 5.3% in dogs with permanent (6 hour) occlusion (probability [p] < 0.001), in which it was transmural. Myocardial contractility was assessed by measuring systolic wall thickening by computer-assisted two-dimensional echocardiography. Before occlusion, this variable averaged 47.9 ± 6.3% in the region to become ischemic. An early salutary effect of reperfusion in the central ischemic zone was seen as a decrease in wall thinning from −11.9 ± 2.9%, 90 minutes after occlusion, to −7.4 ± 2.0%, 4 hours after reperfusion, contrasted with a change from −6.2 ± 3.3%, 90 minutes after occlusion, to −11.7 ± 3.3%, 6 hours after occlusion in the permanently occluded group (p < 0.05). Active thickening was not observed until 72 hours of reperfusion (13.1 ± 4.6%); this increased to 19.5 ± 2.8% at 14 days, compared with 1.5 ± 5.9% in the permanently occluded group at this time (p < 0.05). However, preocclusion values were not achieved in the reperfused group. Some recovery of ATP in the salvaged subepicardium was also noted, with return of levels from 8.0 ± 1.9 nmol/mg protein, 90 minutes after occlusion, to 13.2 ± 1.8 nmol/mg protein, after 4 hours of reperfusion (p < 0.05); however, 7 days were required for recovery approaching preocclusion values of 34.9 ± 1.9 nmol/mg protein.

Thus, reperfusion after 2 hours of coronary occlusion resulted in recovery of jeopardized myocardium, in which the deterioration of function observed in nonreperfused tissue was reversed and biochemical improvement occurred over the course of 2 weeks. Computer-assisted two-dimensional echocardiography, a noninvasive but quantitative technique, appears well suited to monitor the rate of functional recovery of myocardium salvaged by reperfusion.

It has been known since the classic experiments of Tennant and Wiggers (1) that coronary occlusion produces a nearly immediate loss of contractility of the ischemic myocardium. Although an occlusion of less than 20 minutes generally does not produce necrosis (2), studies in several laboratories (3–9) have shown that occlusion as short as 15 minutes yields contractile, biochemical and structural abnormalities that fail to return to normal by 72 hours. Recent clinical studies demonstrating the feasibility of coronary reperfusion by thrombolysis (10–12) or coronary artery bypass grafting was done during the tenure of Dr. Kloner as an Established investigator from the American Heart Association, Dallas, Texas and with funds contributed in part by the Massachusetts Heart Association, Boston, Massachusetts.

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(13) in the early stages of acute myocardial infarction have renewed interest in the functional and biochemical properties of salvaged myocardium. In the clinical setting, it is unlikely that reperfusion by thrombolysis or surgery would often take place less than 2 hours after the onset of coronary occlusion. Studies evaluating the time course of functional recovery after several hours of coronary occlusion have been limited (12, 14-17). Real-time two-dimensional echocardiography provides a readily accessible noninvasive technique that allows quantitative analysis of regional wall motion around the entire left ventricular circumference (18). Of the various contractile variables that may be measured, systolic wall thickening appears to be the most reproducible (19) and most accurate in defining areas of ischemia (18).

The relationship between ischemia-induced loss of myocardial function and loss of high energy phosphate stores is controversial, but several investigators (4,20,21) have noted close correlation between loss of adenosine triphosphate (ATP) and mechanical function after brief periods of ischemia. ATP recovers gradually after brief occlusion (4,13) but creatine phosphate recovers more rapidly. The rate of recovery of high energy phosphate stores after longer periods of ischemia has not been clearly defined.

Accordingly, the purpose of this study was to characterize the extent of myocardial salvage by reperfusion after a 2 hour coronary occlusion and the extent and rate of its mechanical and biochemical recovery by analysis of two-dimensional echocardiographic, computer-derived, regional wall thickening, as well as myocardial ATP and creatine phosphate concentrations during periods of reperfusion up to 2 weeks.

**Methods**

**Animal preparation and instrumentation.** Forty-two mongrel dogs weighing 10.0 to 26.8 kg were anesthetized with thiamylal sodium (20 mg/kg intravenously) and ventilated with a Harvard respirator adjusted to maintain physiologic blood gas values. Morphine sulfate (approximately 1 mg/kg per hour intramuscularly) was also given at induction and throughout the remainder of the experiment to maintain adequate anesthesia. A thoracotomy was performed in the left fifth intercostal space, the lungs retracted and the heart supported in a pericardial cradle. Polyvinyl catheters were placed in the left internal jugular vein for fluid and drug administration, the left atrium for injection of radioactive microspheres for determination of regional myocardial blood flow and the left internal carotid artery for blood pressure recording and withdrawal of the microsphere reference samples. A segment of the left anterior descending coronary artery was dissected free of surrounding epicardium proximal to the first major diagonal branch.

**Experimental protocol.** All of the dogs were subjected to an occlusion of the proximal left anterior descending artery with a Schwartz atrumatic vascular clamp. The occlusion was maintained permanently by ligating the vessel or reperfusion was instituted 2 hours after occlusion by releasing the clamp. Fifteen dogs were sacrificed at 6 hours (8 reperfusion and 7 permanent occlusion); 6 were sacrificed at 7 days (all reperfusion) and 11 were sacrificed at 14 days (5 reperfusion, 6 permanent occlusion); and 10 dogs died before the time they were to be sacrificed and their results are not included. Lidocaine was administered 15 minutes before coronary occlusion in all of the dogs to reduce periocclusion arrhythmias (2.7 mg/kg intravenous bolus, followed in 10 minutes by a 1.3 mg/kg bolus, followed by an infusion of 0.7 mg/kg per min for 1 hour after occlusion).

Heart rate and arterial and left atrial pressures were recorded before occlusion, 15 and 90 minutes after occlusion and just before sacrifice. In 10 of the dogs sacrificed at 6 hours, radioactive microspheres (cesium-141, scandium-46, or stannum-113) were injected for determination of regional myocardial blood flow 90 minutes after occlusion and 2 hours after reperfusion, as previously described (22).

**In vivo myocardial biopsy specimens for ATP and creatine phosphate determination** were obtained 90 minutes after occlusion and at the time of sacrifice in 31 of 32 dogs (1 dog died before the samples could be obtained) using a technique recently described (4). Open chest two-dimensional short-axis echocardiograms were obtained at the midpapillary muscle position 90 to 95 minutes after occlusion and just before sacrifice in all of the dogs, and at 24, 48 and 72 hours by closed chest technique in the dogs sacrificed at 7 days. In these studies, blood flow was measured first, followed by echocardiography and then biopsy. In the 6 hour group, immediately before sacrifice, monastral blue (1 mg/kg) was injected into the left atrial catheter with the coronary artery occluded for determination of the in vivo area at risk. This was not done in those animals sacrificed later, because of a possible reduction in the apparent area at risk with time due to the development of collateral vessels.

Before sacrifice, the dogs were reanesthetized, the chest re-opened and final hemodynamic, echocardiographic and biochemical determinations were made. The heart was then arrested in diastole by potassium chloride injection and excised. The left ventricle was dissected free of surrounding tissue, its surface sprayed with liquid freon to allow even sectioning and sliced into 4 mm transverse sections. The in vivo area at risk (the area unstained by monastral blue) and the area of necrosis (the area unstained by triphenyltetrazolium chloride) were determined by planimetry, as previously described (23). Approximately 1 g of epicardial and endocardial tissue sections were obtained for regional myocardial blood flow determination from the ischemic and normal zones, as defined by the area at risk technique (23).

**Echocardiographic analyses.** Echocardiograms were obtained using an ATL model 850A scanner and a 3.0 MHz transducer. Images were recorded on TDK video cassettes using a Panasonic NC-8200 recorder for later stop-frame analysis. A saline-filled glove was placed between the epicardium and the transducer for all open chest recordings to place the epicardial surface within the focal zone. Closed chest images were obtained with the dog in the right lateral decubitus position and with the transducer directed through a "window" created by resection of the left fifth rib. Analysis was not performed on one dog for the closed chest periods because of poor quality images.

**End-diastolic and end-systolic epicardial and endocardial images were entered for computer analysis using the onset of the Q wave in lead II to define end-diastole and the peak of the T wave to define end-systole.** Images were traced by an observer (who at
the time of tracing was unaware of how the dogs had been treated) either directly from the video display (ATL model 315A) for three to six consecutive cardiac cycles or after 5 x 7 inch (12.7 x 17.8 cm) enlargements from Polaroid XII/780 were obtained and transferred by way of digitized sound pen to a VAX computer system with Tektronix 4014 terminal display. Percent systolic wall thickening at 2° intervals was calculated with a radial contraction model using the endocardial end-diastolic center of mass as the center point and the epicardial center of mass and midseptal point to align the end-diastolic and end-systolic contours and to define the 0° reference point.

Percent systolic wall thickening was calculated as:

\[
\text{Wall thickness (end-systolic)} - \text{Wall thickness (end-diastolic)}
\times \frac{100}{\text{Wall thickness (end-diastolic)}}
\]

Normal systolic wall thickening for each radius was defined by the mean value obtained from preocclusion images of all dogs and expressed as a percent. Abnormally reduced systolic wall thickening for any given radius was defined as a degree of thickening that was more than 2 standard deviations less than the normal value. Regions for analysis of abnormal contractility were arbitrarily defined from the postocclusion images as follows (Fig. 1 and 2): zone A as the central 45° of the area of systolic thinning; zone B as the region of thinning adjacent to, but excluding zone A; zone C as that region of myocardium in which thickening was less than normal, as defined above; and zone D as the normal zone. Changes in contractility as a function of time were then expressed as changes in percent systolic wall thickening within these regions and the extent of these regions (expressed in degrees).

Biochemical analysis. Biopsy material was rinsed with iced saline solution, frozen by immersion in freon within 10 seconds and stored at −70°C until the time of analysis. No deterioration of ATP or CP levels is seen when tissue is frozen this soon after biopsy (25). The location of biopsy specimens in relation to the areas at risk and of necrosis, respectively, was determined by comparison of the site of biopsy with areas of nonstaining by the monastral blue and triphenyltetrazolium chloride techniques, respectively. Determinations of ATP and creatine phosphate were performed using methods previously described (4) and the results expressed in nmol/mg cardiac protein.

Statistical analysis. Statistical analysis was performed using a Hewlett-Packard HP 9815A computer for Student’s t tests, and also for analysis of variance when sequential values for the same dogs were compared. All values are expressed as mean ± standard error, unless otherwise indicated.

Results

Of the 42 dogs initially entered into the study, 10 died before sacrifice: of these, 8 dogs died suddenly after surgery (6 permanent occlusion, 2 reperfusion) 1 died of ventricular fibrillation early during reperfusion and 1 died of infection (reperfusion). The results are based on the 32 surviving animals.

Area of necrosis as a function of the area at risk. The percents of left ventricular mass at risk of necrosis in the reperfusion and permanent occlusion groups were compa-

Figure 1. End-systolic echocardiograms demonstrating improvement of contractile function after 2 weeks of reperfusion. A = preocclusion, B = 2 hours postocclusion; C = 2 weeks after reperfusion in a dog subjected to a 2 hour occlusion of the left anterior descending artery followed by reperfusion. ■ = Outline of endocardial and epicardial borders. Letters A and D indicate zones A and D. Arrows indicate systolic wall thickness in zone A: note thickening between panels B and C.
Myocardial contractility. Before occlusion, the myocardium in the region to become ischemic exhibited a mean systolic wall thickening of 47.9 ± 6.3%. Ninety minutes after occlusion, percent systolic wall thickening in zone A (Fig. 4A) decreased to −11.9 ± 2.9% (thinning) in the reperfusion group and −6.2 ± 3.3% in the permanent occlusion group (p = NS; reperfusion versus permanent occlusion groups). At 6 hours, further thinning was observed in the permanent occlusion group (−11.7 ± 3.3%). In this group systolic thinning gradually resolved, but little active thickening (1.5 ± 5.9%) was observed even after 2 weeks. Return of myocardial contractility with reperfusion was seen at the first determination carried out after 4 hours of reperfusion (that is, 6 hours after occlusion) as a decrease in thinning to −7.4 ± 2.0% (change compared with the permanent occlusion group, p < 0.05). Active thickening did not occur until after 72 hours of reperfusion, however, and remained depressed at 14 days (19.5 ± 2.8 versus 50.0 ± 4.9% preocclusion; p < 0.05).

In zone B (that is, the region of myocardial thinning adjacent to the central 45° of the area of systolic thinning) in animals with permanent occlusion there was some recovery in percent systolic wall thickening at 14 days (21.3 ± 4.4%) although recovery was incomplete (preocclusion control = 44.1 ± 6.1%) (Fig. 4B). In the reperfused dogs, recovery of percent systolic wall thickening in zone B paralleled that in zone A, but active thickening occurred earlier (7.6 ± 1.5% at 6 hours) and recovery at 2 weeks appeared nearly complete (39.5 ± 5.8 versus 45.0 ± 5.2% preocclusion, p = NS). In zone C (that region of myocardium in which thickening was less than normal), recovery in both the reperfused and permanently occluded groups was similar to that in zone B and was nearly complete at 14 days.

The extent of myocardium exhibiting thinning 90 minutes after occlusion averaged 113.8 ± 19.4° in the dogs with permanent occlusion (Fig. 5). This decreased to 43.2 ± 22.3° at 2 weeks, but was still abnormal, because before occlusion less than 15° of the myocardium exhibited thinning. In the reperfused dogs, the extent of myocardial thinning decreased from 120.2 ± 17.3° 90 minutes after occlusion to 74.2 ± 17.3° after 4 hours of reperfusion (6 hours after the initial occlusion) and continued to decrease rapidly over the next 3 days to reach a low value of 3.6 ± 7.2° at 72 hours.

Hemodynamics. Preocclusion values for heart rate, blood pressure and mean left atrial pressure for the 6 hour dogs were 105 ± 10 beats/min, 138 ± 14/97 ± 8 mm Hg and 6 ± 2 mm Hg, respectively (Table 1). Although the heart rate was slightly lower and the systolic blood pressure slightly higher in the reperfusion group than the permanent occlusion group, there were no statistical differences in values between groups (p ≥ 0.20). Fifteen minutes after occlusion, heart rate and mean left atrial pressure had increased, and blood
pressure had decreased. Ninety minutes after occlusion and during the time of early reperfusion, heart rate and systolic systemic blood pressure had nearly returned to their preocclusion values, but mean left atrial pressure remained elevated. There was no statistical difference in these values between treatment groups. Thus, there was no significant difference in preload as approximated by mean left atrial pressure, nor in afterload, as approximated by systemic blood pressure, between treatment groups during the first 6 hours of the experiment. Hemodynamics during the first 6 hours for dogs with long-term occlusion and reperfusion times were similar to that for 6 hour dogs.

**Myocardial high energy phosphate stores.** Myocardial ATP concentration in nonischemic myocardium was 33.5 ± 1.6 nmol/mg protein. At 90 minutes after coronary occlusion, ATP decreased to 10.6 ± 2.1 nmol/mg protein in the subendocardium and 9.4 ± 1.8 nmol/mg protein in the subepicardium (Fig. 6). At 6 hours, ATP in the dogs with permanent occlusion decreased further to 8.9 ± 2.3 nmol/mg protein in the subendocardium and 7.4 ± 1.8 nmol/mg protein in the subepicardium. Partial recovery of ATP in the nonnecrotic subepicardium salvaged by reperfusion was noted as early as 4 hours after reperfusion (13.3 ± 2.2). Return to preocclusion values was achieved by 7 days. There was less of an increase in ATP levels obtained from the subendocardium in the reperfused group and from the subendocardium and subepicardium in the permanent occlusion group noted after 14 days.

**Creatine phosphate in nonischemic myocardium** averaged 61.8 ± 4.4 nmol/mg protein. After 90 minutes of...
occlusion, creatine phosphate decreased to levels of 8.4 ± 4.2 nmol/mg protein in the subendocardium and 9.2 ± 2.9 nmol/mg protein in the subepicardium. In the permanently occluded group, creatine phosphate returned to levels slightly, though not statistically, below normal at 14 days (Fig. 7). With reperfusion, recovery of creatine phosphate was more rapid than that of ATP, approaching preocclusion values in both subendocardial and subepicardial samples after 6 hours (Fig. 7).

**Regional myocardial blood flow.** Ninety minutes after coronary occlusion, blood flow to the nonischemic subendocardium and subepicardium was 0.85 ± 0.09 and 0.85 ± 0.09 ml/min per g, respectively, and did not change after 2 hours of reperfusion. After coronary occlusion, blood flow to the ischemic subendocardium and subepicardium decreased to 0.13 ± 0.03 and 0.21 ± 0.02 ml/min per g, respectively. After 2 hours of reperfusion, blood flows recovered, but only partially, to 0.43 ± 0.09 and 0.54 ± 0.12 ml/min per g, respectively (Table 2).

### Table 1. Hemodynamics (dogs sacrificed at 6 hours)

<table>
<thead>
<tr>
<th>Time</th>
<th>Perm Occl</th>
<th>Reperf</th>
</tr>
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<tbody>
<tr>
<td>Preocclusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>112 ± 9</td>
<td>98 ± 8</td>
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<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>126 ± 8</td>
<td>148 ± 13</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>93 ± 8</td>
<td>100 ± 7</td>
</tr>
<tr>
<td>Mean left atrial pressure (mm Hg)</td>
<td>5 ± 1</td>
<td>6 ± 2</td>
</tr>
<tr>
<td>Occlusion</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15 Minutes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>129 ± 10</td>
<td>104 ± 9</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>120 ± 9</td>
<td>141 ± 12</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>94 ± 8</td>
<td>97 ± 6</td>
</tr>
<tr>
<td>Mean left atrial pressure (mm Hg)</td>
<td>8 ± 1</td>
<td>8 ± 2</td>
</tr>
<tr>
<td>90 Minutes</td>
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<td></td>
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<tr>
<td>Heart rate (beats/min)</td>
<td>99 ± 8</td>
<td>97 ± 7</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>128 ± 10</td>
<td>147 ± 12</td>
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<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>93 ± 8</td>
<td>92 ± 5</td>
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<tr>
<td>Mean left atrial pressure (mm Hg)</td>
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<td>8 ± 2</td>
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<tr>
<td>330 Minutes</td>
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<td></td>
</tr>
<tr>
<td>Heart rate (beats/min)</td>
<td>106 ± 4</td>
<td>109 ± 10</td>
</tr>
<tr>
<td>Systolic blood pressure (mm Hg)</td>
<td>124 ± 9</td>
<td>136 ± 9</td>
</tr>
<tr>
<td>Diastolic blood pressure (mm Hg)</td>
<td>87 ± 6</td>
<td>92 ± 5</td>
</tr>
<tr>
<td>Mean left atrial pressure (mm Hg)</td>
<td>9 ± 2</td>
<td>10 ± 2</td>
</tr>
</tbody>
</table>

Perm Occl = permanent occlusion; Reperf = reperfusion.

**Discussion**

Restoration of blood flow to transiently ischemic myocardium does not bring immediate restoration of function. However, recently it has become appreciated that this recovery may be greatly delayed (3–8) and transiently ischemic myocardium may act as if it has been "stunned" for days (26). In the clinical setting after coronary occlusion, a minimum of 2 to 4 hours have usually passed by the time restoration of coronary blood flow by thrombolysis or coronary artery bypass grafting can be achieved. Animal studies suggest that after such a period of ischemia, some myocardial necrosis has already occurred (5,6,27). However, Reimer and Jennings (27) have shown that restoration of blood flow at this time may still salvage considerable quantities of myocardium. The elucidation of the functional and biochemical properties of such salvaged myocardium is critical to determining the ultimate impact that reperfusion will have on improving pump function. The present study ex-

![Figure 5](image-url) Extent of systolic thinning (zones A and B) Shown on the abscissa is time after coronary occlusion and on the ordinate, the number of arc degrees of myocardium exhibiting systolic thinning. No values were obtained in dogs with permanent occlusions between 6 hours and 14 days.
Figures 6. Recovery of subepicardial (top) and subendocardial (bottom) adenosine triphosphate (ATP) with reperfusion. Shown on the abscissa is time after occlusion and on the ordinate, ATP in nmol/mg cardiac protein. No values were obtained for dogs with permanent occlusion between 6 hours and 14 days.

Restoration of ventricular contractile function. With the aid of computer-assisted sector scanning to quantify subtle changes in regional wall thickening, significant improvement in function (that is, less thinning) could be demonstrated after 4 hours of reperfusion. The return of active thickening was found to occur within 48 to 72 hours. These data are in general agreement with the sonomicrometer data of Theroux et al. (16), but neither these investigators nor others (5, 12, 9) have demonstrated a significant early (less than 24 hours) improvement in function with reperfusion.

There was a more gradual recovery of function when reperfusion was carried out after 2 hours of occlusion than after a 15 minute occlusion (4,6). Return of myocardial function, as reflected by systolic wall thickening in areas that exhibited systolic thinning 90 minutes after occlusion, recovered to less than half of the preocclusion value (of thickening) at 7 days and remained abnormal at 14 days (Fig. 4A); this is in contrast to full recovery of systolic function observed when reperfusion was carried out after 15 minutes of occlusion (6). Return of function in the reperfused region was, of course, much greater than that which occurred in the myocardium subserved by a permanently occluded vessel, as described herein and by other investigators (28–31).

Improvement in myocardial contractile function, as reflected in systolic wall thickening after reperfusion after 2 hours of occlusion, also occurred at the margins of the ischemic zone. However, significant improvement in function was noted in this area even after permanent occlusion (Fig. 4B). This apparent recovery may be attributed to diminished thinning in the central ischemic zone (zone A) consequent to decreasing compliance of the infarct (32) and its influence on the motion of segments of myocardium at the margins of the ischemic zone (zone B), the so-called tethering effect (33,34).
Biochemical improvement. Subepicardial ATP concentrations after 90 minutes of coronary occlusion are depressed to a greater extent (29.3% of control) than after a 15 minute occlusion (63.6% of control) and recovery takes longer, although it does return to normal by 7 days (Fig. 6, top). ATP also increased in the subendocardium of the reperfused dogs and to a lesser extent in the area of infarction in the dogs with permanent occlusions by 14 days (Fig. 6, bottom). The latter might result from the influx of viable cells into the areas of necrosis during healing. Creatine phosphate levels were also found to be depressed more severely after 90 minutes (15.2% of control) than after 15 minutes of ischemia (35.2% of control) (3,4,9). However, full recovery of creatine phosphate was seen after 4 hours of reperfusion.

Myocardial blood flow. After reperfusion, myocardial blood flow did not return to normal, either in myocardium that underwent necrosis or that was salvaged by reperfusion. In the former area, this may be the result of the "no reflow" phenomenon (35), although in the latter it may reflect the decreased oxygen demand of weakly contracting myocardium.

Clinical implications. This study demonstrates the beneficial effects of reperfusion after 2 hours of coronary occlusion. These include not only reduction of infarct size, but also the restoration of function and high energy phosphate stores in salvaged myocardium; however, the changes were quite gradual. These findings have important clinical implications. The possible effectiveness of reperfusion or any other intervention designed to decrease infarct size, cannot be judged by its immediate effect. Even after successful restoration of coronary blood flow by surgical or thrombolytic reperfusion and resultant salvage of myocardium, days of prolonged and vigorous supportive measures may be required before functional recovery takes place. The rate of this recovery may be assessed by noninvasive studies, and serial two-dimensional echocardiography appears to be suited for this purpose.

Table 2. Summary of Regional Myocardial Blood Flows

<table>
<thead>
<tr>
<th></th>
<th>Ischemic</th>
<th>Nonischemic</th>
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<tbody>
<tr>
<td>Subendocardium</td>
<td>0.13 ± 0.03</td>
<td>0.85 ± 0.09</td>
</tr>
<tr>
<td>90 minutes after occlusion</td>
<td>0.43 ± 0.09†</td>
<td>0.91 ± 0.12</td>
</tr>
<tr>
<td>2 hours with reperfusion</td>
<td>0.54 ± 0.12*</td>
<td>0.84 ± 0.13</td>
</tr>
<tr>
<td>Subepicardium</td>
<td>0.21 ± 0.02</td>
<td>0.85 ± 0.09</td>
</tr>
<tr>
<td>90 minutes after occlusion</td>
<td>0.54 ± 0.12*</td>
<td>0.84 ± 0.13</td>
</tr>
<tr>
<td>2 hours with reperfusion</td>
<td>0.21 ± 0.02</td>
<td>0.85 ± 0.09</td>
</tr>
</tbody>
</table>

Data obtained from 10 dogs sacrificed at 6 hours, 6 with reperfusion. All values expressed in ml/min per g as mean ± standard error. Samples in the ischemic zone in each were derived from an average of two samples in each dog.

\*p < 0.01 versus after occlusion; †p < 0.005 versus postocclusion; ‡p < 0.01 versus nonischemic
We gratefully acknowledge the technical assistance of John Howell, Kevin Alker and William Hamlon and the secretarial assistance of Nancy Watterson.

The dogs used in this study were maintained in accordance with the guidelines of the Committee on Animals of the Harvard Medical School and those prepared by the Committee on Care and Use of Laboratory Animals of the Institute of Laboratory Animal Resources, National Research Council (DHEW Publication No. [NIH] 78-23, revised 1978).

References


