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Recovery of regional myocardial dysfunction after successful coronary angioplasty early after a non-Q wave myocardial infarction

More aggressive therapy has been suggested for patients who have a non-Q wave myocardial infarction (MI) because of the frequency of subsequent unstable angina, recurrent MI, and high mortality rate compared to patients with Q wave MI. The present study was undertaken to investigate the effect of coronary angioplasty on regional myocardial function of the infarct zone in patients with angina early after a non-Q wave MI. The study population consisted of 36 patients undergoing successful coronary angioplasty within 30 days of a non-Q wave MI, in whom sequential left ventricular angiograms of adequate quality were obtained before the initial procedure and at follow-up angiography. The global ejection fraction increased significantly from $60 \pm 9\%$ to $67 \pm 6\%$ ($p = 0.0003$). This significant increase in the global ejection fraction was primarily due to a significant improvement in the regional myocardial function of the infarct zone. The results of the present study show not only that ischemic attacks early after a non-Q wave MI may lead to prolonged regional myocardial dysfunction but more important that this depressed myocardium has the potential to achieve normal contraction after successful coronary angioplasty. (*AM HEART J* 1990;120:261.)

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The reported incidence of non-Q wave myocardial infarction (MI) varies between 20% and 36% of all acute MI.¹⁻⁵ Although non-Q and Q wave MI as classified by ECG results cannot always be anatomically differentiated,^{6,7} it seems likely that they differ clinically, physiologically, and prognostically as discussed by Spodick.⁸ In particular, non-Q wave MI is generally associated with smaller amounts of myocardial necrosis, better left ventricular function, and a lower incidence of in-hospital death when com-

pared to Q wave MI. Despite these initially favorable features, evidence has accumulated that the long-term mortality rate in these patients is similar to or even greater than that in patients with Q wave MI. The relatively high mortality rate of patients with non-Q wave MI seems to be related to unstable angina or subsequent recurrent MI in the same area^{1-3,6,9-13} and may be prevented if recurrent MI can be averted with revascularization. These findings have understandably led some to recommend more aggressive evaluation and treatment strategies for survivors of non-Q wave MI.

Results of previous studies have shown that regional myocardial dysfunction, observed during acute ischemic syndromes, improves after coronary blood flow is restored by coronary angioplasty. In the setting of preinfarction angina¹⁴ and in the first few

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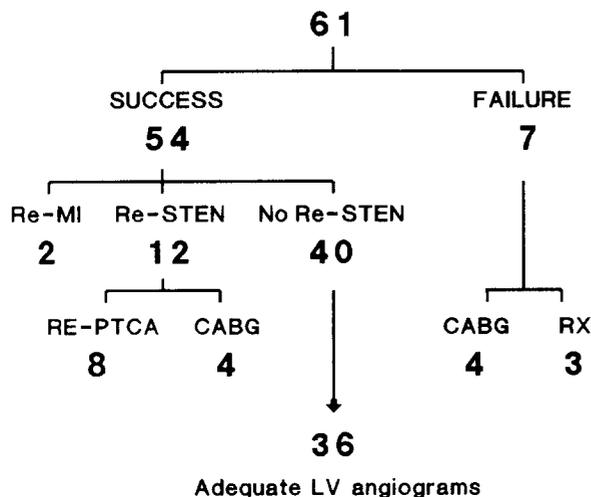


Fig. 1. Clinical follow-up data obtained at mean interval of 20 (range 3 to 59) months in patients who underwent early coronary angioplasty after sustained non-Q wave MI. Patients selected for study were those who underwent successful coronary angioplasty without angiographic restenosis (*Re-Sten*) or late major clinical events during follow-up and in whom sequential left ventricular (*LV*) angiograms of sufficient quality were available. *Re-MI*, recurrent myocardial infarction; *Re-PTCA*, repeat coronary angioplasty; *CABG*, coronary artery bypass surgery; *Rx*, controlled by pharmacologic treatment.

hours of acute MI,¹⁵ reperfusion with coronary angioplasty has resulted in improvement in regional myocardial function. In contrast, the impact of therapeutic interventions in patients with postinfarction angina remains unsettled, particularly in patients with sustained non-Q wave MI. Although there have been several reports suggesting that revascularization with coronary angioplasty or coronary artery bypass surgery can be performed safely and effectively early in the course of non-Q wave MI,¹⁶⁻²⁰ the assessment of regional myocardial function in the infarct zone and the role of coronary angioplasty in salvaging function in this setting have not been established. The present study was therefore undertaken to investigate the effect of coronary angioplasty on regional myocardial function of the infarct zone in patients with angina early after a non-Q wave MI.

METHODS

Patients. Between January 1982 and January 1987, a total of 116 patients underwent coronary angioplasty for angina, either at rest or during submaximal exercise despite optimal pharmacologic therapy, after a non-Q wave MI. They represented 8% of our total coronary angioplasty population during this period. Of these 116 patients, 61 underwent early coronary angioplasty during

Table I. Clinical characteristics

Characteristics	
No.	36
Men/women	28/8
Age (median, yr)	56 (range 32-72)
Anterior/inferior non-Q MI	24/12
Peak CK enzyme level (median, U/L)	389 (range 243-892)
Peak CK-MB (median, U/L)	42 (range 12-94)
Stable angina pectoris	7
Unstable angina pectoris	29
Therapy before PTCA	
Triple therapy (intravenous NTG)*	34 (16)*
Double therapy	2
Time from MI to PTCA (median, days)	14 (range 2-30)

CABG, coronary artery bypass graft; PTCA, percutaneous transluminal coronary angioplasty; MI, myocardial infarction; CK, creatinine phosphokinase; NTG, nitroglycerin.

*Optimal pharmacologic therapy consisted of beta blocker, calcium antagonist, and nitrates, including 16 patients who were treated with intravenous nitroglycerin.

Table II. Angiographic characteristics

Characteristics	
Single-vessel disease	25 (69%)
Multivessel disease	11 (31%)
Total occlusion	5 (14%)
Collateral circulation	28 (78%)
Single-vessel dilatation	32 (89%)
Multivessel dilatation	4 (11%)
Dilated coronary artery (n = 40)	
Left anterior descending	25 (62.5%)
Left circumflexus	7 (17.5%)
Right	8 (20%)

their hospital stay after sustained non-Q wave MI. The obstructed vessel was successfully dilated in 54 of the 61 patients (89%). All patients were followed at the outpatient clinic. Clinical follow-up data obtained at a mean interval of 20 (range 3 to 59) months are shown in Fig. 1. Patients selected for the study were those who underwent successful coronary angioplasty early after a non-Q wave MI without angiographic restenosis or late major clinical events during follow-up and in whom sequential left ventricular angiograms of sufficient quality to allow automated contour analysis before coronary angioplasty and at follow-up were available. Thirty-six patients fulfilled these criteria and formed our study population (Fig. 1). Clinical and angiographic data are summarized in Tables I and II.

Non-Q wave MI was defined in this study as prolonged chest pain compatible with acute MI, associated with electrocardiographic ST segment and T wave abnormalities without progression to pathologic Q waves but with abnormal elevation of the creatinine kinase level (at least twice the normal value) before any intervention. Postinfarction angina was considered unstable if it occurred at rest, lasted for at least 15 minutes, and was associated with ECG evidence of myocardial ischemia without evidence of fur-

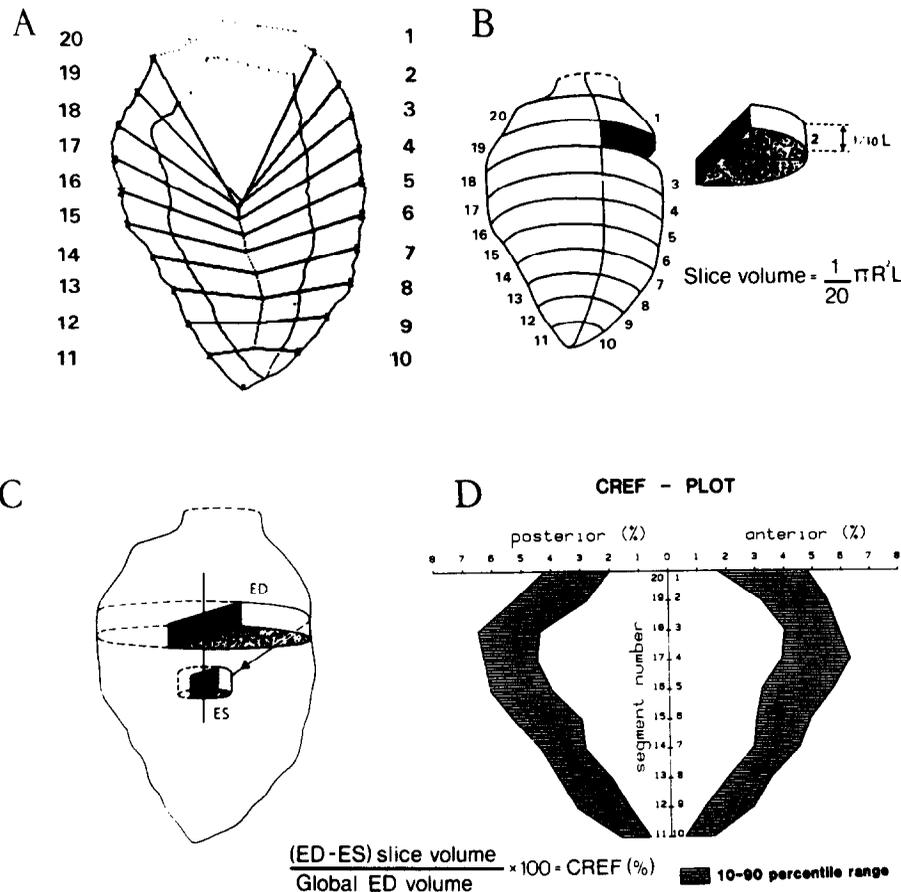


Fig. 2. **A**, Example of computer output showing end-diastolic and end-systolic contours of 30-degree right anterior oblique view of left ventriculogram. Systolic regional wall displacement was determined along a system of 20 coordinates based on pattern of actual endocardial wall motion in normal individuals²² and generalized as mathematical expression amenable to automatic data processing.^{23, 25} **B**, Left ventricular end-diastolic cavity is divided into 20 half slices. Volume of each half slice is computed according to given formula, R is radius and L is left ventricular long-axis length. **C**, Regional contribution to global ejection fraction ($CREF$) is determined from systolic decrease of volume of half slice, which corresponds to particular wall segment. Systolic volume change is mainly consequence of decrease of radius (R) of half slice. When normalized for end-diastolic volume, systolic segmental volume change was considered as a parameter of regional pump function. **D**, Shaded zones represent tenth to ninetieth percentiles area of $CREF$ values in normal individuals. X axis displays $CREF$ values of anterior and inferoposterior wall areas (%); Y axis shows segment numbers of anterior wall (1 to 10) and inferoposterior wall (11 to 20).

ther myocardial necrosis. Angioplasty was considered successful when a reduction in the severity of the obstruction to less than 50% luminal diameter narrowing was achieved with abolition of acute ischemic symptoms without progression to MI, emergency surgery, or death. Restenosis at follow-up was defined as a decrease of ≥ 0.72 mm in minimal luminal diameter with respect to the postangioplasty situation.²¹ After the procedure patients were monitored for 24 hours in the medium-care unit. All were treated with 60 mg nifedipine and 500 mg acetylsalicylic acid daily over a period of 6 months. During this follow-up period six patients received additional beta blockers, three of them in combination with nitrates. Follow-up coronary and left ventricular angiography and exercise thallium-201 scintigraphy were performed at a mean of 5 months.

Quantitative analysis of left ventricular and coronary angiography. Global and regional left ventricular function was studied from the 30-degree right anterior oblique projection by means of an automated hard-wired endocardial contour detector. This method of analysis has previously been described in detail.²²⁻²⁵ The analysis of regional left ventricular function was based on automated, high-resolution, frame-to-frame edge detection of the left ventricular contour. This system allows fast and reliable acquisition of a single left ventricular contour, every 20 msec (50 frames/sec), all over a complete cardiac cycle. Fig. 2 shows examples of the end-diastolic and end-systolic contours of the left ventriculogram and the segmental contribution to the global ejection fraction as displayed by the analysis system. Quantitative analysis of the dilated coronary segment be-

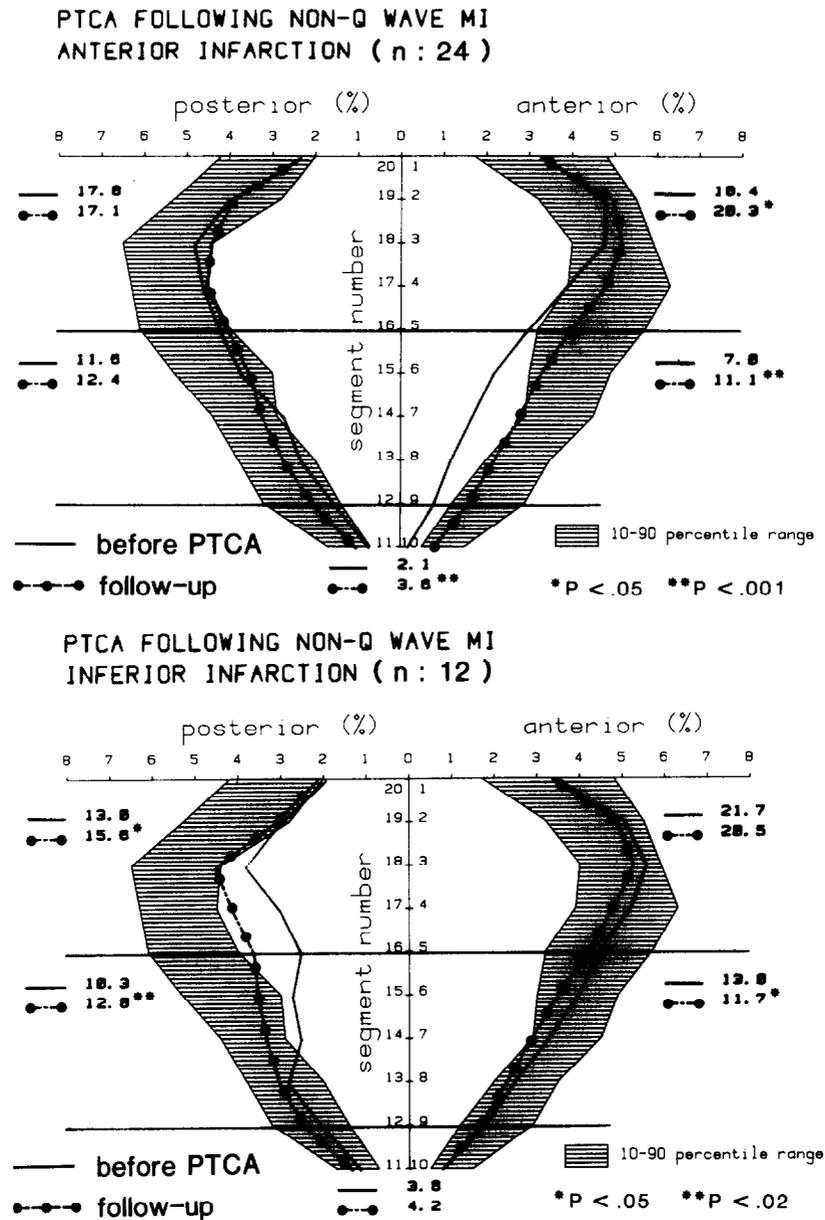


Fig. 3. Sequential changes in regional contribution to global ejection fraction, before angioplasty (solid line) and at follow-up angiography (dotted line), in patients with anterior (top) and inferior (bottom) non-Q wave MI undergoing successful coronary angioplasty. Initially depressed regional myocardial function of infarct zone has potential to achieve normal contraction after adequate reperfusion with coronary angioplasty, resulting in significant increase in global ejection fraction.

fore and after the angioplasty procedure and at follow-up coronary angiography was carried out with the computer-assisted cardiovascular angiography analysis system, which has been described in detail previously.^{26,27}

Exercise thallium-201 scintigraphy. Patients performed symptom-limited exercise on the bicycle ergometer with stepwise increments of 20 W every minute. The three orthogonal leads X,Y, and Z of the Frank lead system were recorded. An ischemic response was defined as at least a 0.1 mV ST segment depression occurring 0.08 second after the

J point. The maximal work load achieved was expressed as a percentage of the normal work load predicted for age, sex, and height. Thallium scintigraphic imaging was performed in the anterior, 45- and 65-degree left anterior oblique views, immediately after injection of 1.5 mCi of thallium-201 at peak stress. The postexercise images were obtained 4 hours later. Images were obtained with a Searle Phogamma V camera (G. D. Searle & Co., Skokie, Ill.) and processed with computer interface as previously described.²⁸ Defects with subsequent redistribution were considered to

represent exercise-induced ischemia. Persistent defects without redistribution were considered to represent infarcted myocardium.

Statistics. Data are expressed as mean \pm standard deviation. Paired Student's *t* tests were applied whenever appropriate. A *p* value of less than 0.05 was considered significant.

RESULTS

Follow-up angiography was performed at a mean of 4.7 (range 2 to 8) months after initially successful coronary angioplasty. The mean diameter and area of stenosis of the dilated coronary artery, determined by means of a computer-assisted quantitative analysis, were respectively $59.4 \pm 10.6\%$ and $83 \pm 17\%$ before the angioplasty procedure, $32.8 \pm 8.7\%$ and $53 \pm 11\%$ immediately after angioplasty, and $36.6 \pm 7.7\%$ and $59 \pm 10\%$ at follow-up angiography.

Quantitative analysis of global and regional left ventricular function. Sequential changes in the global left ventricular function before coronary angioplasty and at follow-up angiography are summarized in Table III. There were no significant changes in heart rate, mean aortic pressure, end-diastolic pressure, and end-diastolic volume. The end-systolic volume, however, decreased significantly from 29 to 24 ml/m², resulting in a significant increase in global ejection fraction from $60 \pm 9\%$ to $67 \pm 6\%$ (*p* = 0.0003). This significant increase in the global ejection fraction was primarily due to a significant improvement in the regional contribution to ejection fraction (CREF) of the infarct zone, as shown in Fig. 3. More detailed analysis of the regional myocardial function (Table IV) further demonstrated that the CREF values of the initially abnormal segments increased significantly from 12.6% to 20.1%, whereas in those segments that were initially normal the regional myocardial function decreased.

Exercise thallium-201 scintigraphy. ECG exercise testing and thallium-201 scintigraphy were carried out in 33 patients (92%), 4.5 (range 2 to 11) months after the angioplasty procedure (Fig. 4). A maximal work load of more than 80% predicted for age, sex, and height was achieved in 91% of the patients. Ninety-one percent of the patients were symptom free during exercise; ischemic ST-T segment depression was induced in 15%, and a reversible thallium-201 perfusion defect in the area supplied by the dilated vessel was documented in 18% of the patients.

DISCUSSION

Although there was a significant improvement in global ejection fraction in our patients, the crucial

Table III. Sequential changes in global left ventricular hemodynamics

Hemodynamics	Before PTCA	Follow-up	<i>p</i> Value
HR (beats/min)	70 \pm 12	78 \pm 17	NS
MAP (mm Hg)	82 \pm 12	85 \pm 9	NS
EDP (mm Hg)	23 \pm 10	19 \pm 8	NS
EDV (ml/m ²)	73 \pm 17	71 \pm 15	NS
ESV (ml/m ²)	29 \pm 12	24 \pm 6	0.006
SV (ml/m ²)	44 \pm 12	47 \pm 11	0.08
EF (%)	60 \pm 9	67 \pm 6	0.0003
CI (L/min/m ²)	3.0 \pm 0.8	3.1 \pm 0.8	NS

HR, heart rate; MAP, mean aortic pressure; EDP, end-diastolic pressure; EDV, end-diastolic volume; ESV, end-systolic volume; SV, stroke volume; EF, global ejection fraction; CI, cardiac index; PTCA, percutaneous transluminal coronary angioplasty; NS, not significant.

Table IV. Quantitative assessment of regional contribution to global ejection fraction (CREF)

	Before PTCA	Follow-up	<i>p</i> Value
Sum of abnormal CREF (%)	12.6 \pm 4.8	20.1 \pm 7.7	10 ⁻⁸
Sum of normal CREF (%)	46.4 \pm 11.9	44.5 \pm 11.9	0.007

question remains whether these differences can be ascribed to the salvage of previously jeopardized myocardium in the area supplied by dilated vessel. Therefore analysis of left ventricular wall motion in the area at risk must be carried out to detect any real benefit of correcting the obstructive lesion. In fact, increased motion of the nonischemic regions may keep the global ejection fraction within normal limits despite severe regional hypokinesia in the ischemic area. As this compensatory augmented motion in the nonischemic area usually subsides chronically, the global ejection fraction has proved to be an unreliable and insensitive measure of assessing either the severity of hypokinesia in an ischemic region or the effect of therapeutic interventions in salvaging function.

The present study constitutes the first analysis of the effect of coronary angioplasty on global and regional left ventricular function at rest in a series of patients with non-Q wave MI. The results show that the initially depressed myocardium is capable of recovering function and has the potential to achieve normal contraction after adequate reperfusion with coronary angioplasty, resulting in a significant increase in global ejection fraction even after the disappearance of compensatory enhanced function of the nonischemic area. This suggests that in some patients reperfusion may need to be supplemented by

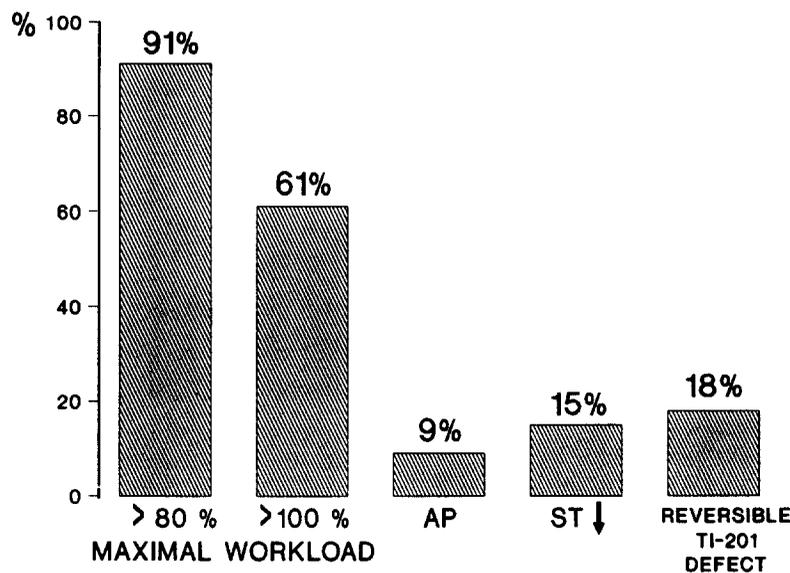


Fig. 4. Results of exercise thallium-201 scintigraphy ($n = 33$), 4.5 (range 2 to 11) months after initially successful angioplasty. Maximal work load of $>80\%$ and $>100\%$ predicted for age, sex, and height was achieved in 91% and 61% of patients, respectively. Majority of patients (91%) were symptom free during test; ST segment depression was documented in 15%, and reversible thallium-201 perfusion defect in area supplied by dilated vessel was observed in 18% of patients.

an additional procedure such as angioplasty to optimize the chances of obtaining full functional recovery. The additional value of angioplasty in preserving left ventricular function might help to explain the observed low mortality rate and other major cardiac events.¹⁷

Factors influencing resting regional myocardial dysfunction. It has been shown experimentally that a severe reduction in coronary blood flow may result in loss of regional contractility without evidence of infarction.^{29,30} In the clinical setting it is important to appreciate these concepts, because the left ventricular dysfunction may be reversed by revascularization, resulting in reduced disability and improved survival.³¹ When myocardial perfusion is chronically reduced but is still sufficient to maintain the viability of the tissue, myocardial function may remain impaired permanently or for as long as myocardial perfusion is inadequate ("hibernating" myocardium).³² There is evidence that during low-flow ischemia, glucose metabolism is increased relative to fatty acid oxidation^{33,34} until flow is too low to permit washout of inhibitory end products of glucose metabolism. Continuation of glucose metabolism with subcritical reduction in blood flow may support cellular viability despite decreased regional myocardial contractility. It is thus possible that in patients with these features, this metabolic state may become chronic and clinically stable.

Chronic impairment of regional myocardial func-

tion may also be due to repeated episodes of transient ischemia that are too brief to cause necrosis, leading to regional depletion of glycogen or high-energy phosphate stores, or they may be the result of reversible injury to other critical myocardial cellular processes that persists for prolonged periods after reperfusion.³⁵ The return of contractile function in the salvaged tissue is not immediate but may require many days. This prolonged postischemic myocardial dysfunction has been referred to as "stunning" of the myocardium. Stunning also occurs as a consequence of longer periods of coronary occlusion in which the most intensively ischemic tissue, generally the subendocardium, undergoes irreversible damage, whereas large quantities of myocardium that are adjacent, usually epicardial, to the necrotic area may survive after reflow occurs.³⁶ The fundamental mechanism responsible for myocardial stunning has not been definitively elucidated. The prolonged biochemical abnormality has been suggested as an explanation for the prolonged mechanical recovery; the adenosine triphosphate content of stunned tissue has been shown to be initially depressed by 50% with only partial recovery to 80% of normal within 3 days.³⁷ Similarly a variety of other biochemical abnormalities have been postulated as the basis for the stunned myocardium: oxygen-derived free radicals,³⁸ abnormal calcium transport by the sarcoplasmic reticulum,³⁹ interruption of the creatine phosphate shuttle,⁴⁰ regional depletion of glycogen or high-en-

ergy phosphate stores, and abnormalities of the cardiac sympathetic nerves.⁴¹

Although the natural history of the change in left ventricular function during the early course of acute non-Q wave MI has not been established, it is possible that the mechanisms of regional myocardial dysfunction in patients with non-Q wave MI may be due to a combination of both phenomena, since spontaneous coronary reperfusion after non-Q wave MI is common⁴ and is frequently associated with subsequent unstable angina and recurrent MI.^{6, 10, 42} Results of several angiographic studies^{4, 9, 43-45} have shown that patients with non-Q wave MI have a low incidence of totally occluded infarct-related vessel and a high incidence of collateral circulation to the area supplied by the infarct-related vessel. The essential finding of these studies is that some degree of perfusion, either antegrade or by means of collateral circulation, is present soon after a non-Q wave MI, although it is insufficient to prevent the initial necrosis. In addition, it is possible that the impairment of contractile function that characterizes both stunned and hibernating myocardium serves as a protective mechanism in that it reduces the oxygen demands of the hypoperfused myocardium and thereby limits ischemia and necrosis. In the present study the incidence of open infarct-related vessel at the time of the angioplasty procedure was 86%, and the incidence of collateral circulation to the infarct area was 78%; all patients were symptomatic with 81% having unstable angina before angioplasty. In this situation the initially depressed regional myocardial function at rest in our series may be due to either chronic underperfusion of the myocardium, to prolonged mechanical recovery following episodes of transient ischemia after sustained non-Q wave MI, or to both mechanisms. Whereas actual ischemia during baseline angiography as a possible explanation for the observed myocardial dysfunction seems unlikely, since no patients had angina in the laboratory and the mean time from the last attack of chest pain to left ventriculography before angioplasty was 38 ± 27 hours.

Limitations. On the other hand, there are several limitations to the study, and the results should be interpreted with this in mind. First, the results may be biased by the selection of patients and because the study was uncontrolled and involved only patients with non-Q wave MI with both recurrent anginal symptoms and anatomy suitable for coronary angioplasty. Therefore the results cannot be extrapolated to the majority of patients with non-Q wave MI. Comparison with the group in which angioplasty was not successful would be meaningless because of the

limited number of patients and the high incidence of major clinical events with subsequent additional interventions in this unsuccessful angioplasty group (Fig. 1).

The lack of left ventricular angiograms immediately after successful angioplasty is another limitation of this study, inasmuch as it means we are unable to determine whether the initially depressed myocardium was due to prolonged postischemic dysfunction or to chronic underperfused myocardium. However, it is possible that left ventricular performance immediately after angioplasty could be influenced by catecholamine stimulation.⁴⁶ Although the natural history of myocardial function in patients with non-Q wave MI remains unsettled, regional myocardial dysfunction might improve spontaneously either as part of a natural healing process or as a result of pharmacologic therapy.^{47, 48} Therefore randomization would have been desirable. However, it is difficult to justify this type of study in our patient population, since these patients constitute a high-risk subgroup because of the presence of ongoing angina, either at rest or during submaximal exercise, despite optimal pharmacologic therapy. Such early postinfarction angina carries a poor short- and long-term prognosis.^{1, 6, 9, 42, 49}

Although differences in pharmacologic treatment before and after the angioplasty procedure may also play a role in the observed difference in left ventricular function, results of the present study show that the regional wall motion improved selectively in the areas supplied by dilated artery rather than in the ventricle as a whole. We believe that the normalization of the antegrade flow after successful coronary angioplasty, as evidenced by repeat angiography, and the sustained symptomatic benefit with no signs of ischemia in the majority of the patients undergoing exercise thallium-201 scintigraphy, is the main reason for the observed recovery of myocardial function, although it is difficult to interpret the results of the thallium test because baseline thallium-201 scintigraphy was not performed.

Clinical implications. The salutary results of revascularization in patients with myocardial dysfunction emphasize the importance of detecting the reversibility of the regional myocardial dysfunction. Determining whether revascularization will improve abnormal resting wall motion has depended on the demonstration of reversible flow abnormalities on exercise thallium-201 scintigraphy⁵⁰ or on evidence of improved wall motion after nitroglycerin infusion,⁵¹ with exercise⁵² or inotropic stimulus, such as postextrasystolic potentiation during contrast or radionuclide angiography,⁵³ or the infusion of a sym-

pathomimetic amine.⁵⁴ Positron emission tomography has also been used to differentiate between normal, ischemic, and infarcted myocardium, as recently reported by several investigators.^{55, 56}

Patients with non-Q wave MI appear to have more residual myocardial mass at risk as determined by exercise scintigraphy.^{4, 9} By means of the F-18-deoxyglucose positron emission tomographic technique in 11 patients, it has been demonstrated that residual myocardial tissue viability in the infarct area is observed in 91% of patients with non-Q wave MI and in only 36% of the patients with Q wave MI.⁵⁷ These findings support the concept of myocardial salvage through recanalization to prevent further loss of myocardium, for one might postulate that these patients are left with an "incomplete MI" with an area of the myocardium "at risk" and might therefore benefit from revascularization of the relevant artery.

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