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Time Course and Extent of Improvement of Dysfunctioning Myocardium in Patients With Coronary Artery Disease and Severely Depressed Left Ventricular Function After Revascularization: Correlation With Positron Emission Tomographic Findings

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OBJECTIVES This study was performed to evaluate the prevalence, time course of recovery and extent of improvement of segments with a positron emission tomographic (PET) flow–metabolism mismatch and match pattern, as well as of PET segments with normal perfusion but with impaired myocardial function.

BACKGROUND Previous studies have shown that scintigraphic techniques evaluating myocardial viability provide predictive information about the improvement of regional wall motion. However, there are little data concerning the time course and extent of improvement of segments according to preoperative scintigraphic patterns.

METHODS Twenty-nine patients with ischemic cardiomyopathy (ejection fraction 18% to 35%) underwent preoperative PET viability assessment and were functionally assessed by two-dimensional echocardiography preoperatively and at 11 days, 14 weeks and >12 months after coronary artery bypass graft surgery.

RESULTS In 168 (70%) of 240 dysfunctional segments, a "normal" scintigraphic pattern was present, whereas a "mismatch" pattern was observed in 24% ($p < 0.01$). Mismatch areas were associated with more severe preoperative wall motion abnormalities and incomplete postoperative recovery. After one year, 31% of normal scintigraphic segments, compared with only 18% of mismatch segments, showed complete functional restoration ($p < 0.05$).

CONCLUSIONS These data suggest that in patients with severe left ventricular dysfunction, a scintigraphic pattern of normal perfusion and normal metabolism is more prevalent than a flow–metabolism mismatch pattern. Functional recovery is more frequent in normal scintigraphic segments, whereas in mismatch segments, postoperative recovery remains incomplete even after one year. (J Am Coll Cardiol 2000;36:1927–34) © 2000 by the American College of Cardiology

It is well established that ischemically compromised myocardium is associated with severe impairment of contractile function and heart failure. However, in contrast to infarct-related or scar tissue, dysfunctioning but viable myocardium has the potential to regain contractile function (1,2). Positron emission tomography (PET) has been reported to be highly specific in differentiating viable from scarred myocardium in patients with chronically dysfunctional myocardium (3,4). The presence of maintained or increased uptake of 18-F-fluorodeoxyglucose (FDG) in segments with reduced nitrogen-13 (N-13) ammonia uptake (flow–metabolism mismatch) is predictive of tissue viability (5,6). In virtually all previous studies, the flow–metabolism mismatch pattern has been used synonymously with reversible contractile dysfunction of "hibernating myocardium"; therefore, postoperative analysis of regional myocardial function was frequently limited to this scintigraphic pattern (3–6).

However, it has also been reported that impaired regional wall motion may occur in the absence of perfusion abnormalities, initiating intense discussion regarding the underlying pathophysiology of dysfunctioning myocardium in ischemic heart disease (7–9). At present, there are no data on the prevalence of dysfunctioning segments with a flow–metabolism mismatch or with normal perfusion and metabolism in patients with severe ischemic left ventricular (LV) dysfunction. Furthermore, there are little data concerning the time course and extent of improvement of dysfunctioning myocardium in relation to the scintigraphic pattern. Thus, this study evaluated the prevalence, time course of recovery and extent of improvement in segments with a flow–metabolism mismatch, as well as in segments with

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Abbreviations and Acronyms

CABG = coronary artery bypass graft surgery
CAD = coronary artery disease
FDG = 18-F-fluorodeoxyglucose
LV = left ventricular
M = scar tissue
MM = myocardium with flow–metabolism mismatch
NN = normal perfused but dysfunctioning myocardium
N-13 = nitrogen-13
PET = positron emission tomography

normal perfusion but with impaired regional myocardial function.

METHODS

Study group. Twenty-nine consecutive patients (27 men and 2 women) with advanced three-vessel coronary artery disease (CAD) and severe LV dysfunction (ejection fraction ≤ 35%) who were referred for surgical revascularization at our institution, were included in this study. All patients gave written, informed consent. Table 1 displays the preoperative clinical and angiographic data. Angiography was performed at a mean of 53 ± 39 days (range 11 to 169, median 39) before the operation.

Positron emission tomography. We performed PET imaging with N-13 ammonia and FDG at a mean of 23 ± 30 days (median 8) before the operation. Patients without known diabetes mellitus were studied in the postprandial state after oral glucose loading with 50 g of glucose. Patients with known diabetes or abnormal glucose tolerance received insulin before and during the imaging sequence according to a standardized protocol (10). After transmission scanning for attenuation correction, rest regional myocardial perfusion imaging with N-13 ammonia (740 MBq) was performed. After a waiting period for N-13 decay, FDG (370 MBq) was injected, and data acquisition was initiated 40 min after tracer injection. Transaxial planes were obtained using a whole-body PET scanner (Siemens CTI 951 or Siemens Exact 47). Attenuation-corrected transaxial emission images were generated from N-13 ammonia and FDG data.

Image analysis. Automated, semiquantitative image analysis was done using a radial three-dimensional maximal activity search based on an interactive definition of the ventricular long axis, with a cardiac analysis program (Munich Heart) developed at our institution (11). A circumfer-

Table 1. Clinical and Angiographic Findings of the 29 Patients

Patient No.	Age (yr)	Angina	Hypertension	Diabetes	CHF	MI	LVEDP (mm Hg)	EF (%)	LMS (%)	LAD (%)*	LCx (%)*	RCA (%)*
1	66	No	Yes	No	Yes	No	28	25		75/90	75	75
2	65	No	Yes	No	Yes	No	19	25		50/90	50/75	90/90
3	68	Yes	No	No	No	No	17	23		75/75	75	75/100
4	63	Yes	No	No	No	No	15	28		75/90	90	75/50
5	51	No	Yes	No	Yes	Yes	17	29		99	75/100	75
6	68	Yes	No	No	Yes	No	17	30		75		90
7	58	Yes	Yes	No	Yes	Yes	33	29		50/100	90/75	90
8	69	Yes	No	No	No	Yes	4	33		90	90	100
9	67	Unstable	No	Yes	No	Yes	11	30		90	100	90
10	44	Yes	Yes	No	No	Yes	28	25		100		100
11	68	Yes	No	No	No	No	11	33		90	50	100
12	65	No	Yes	No	Yes	Yes	12	31		75/90	50/75	75/90/75
13	54	Yes	No	Yes	No	Yes	18	24	75	75	100	75
14	70	No	No	No	Yes	No	9	26	75	75/75	50	50/57
15	65	Yes	Yes	Yes	No	Yes	27	28		100	90	75
16	85	No	No	Yes	Yes	Yes	20	30		100	75	75/50
17	44	Yes	Yes	No	No	Yes	19	33		100	90/90	90
18	64	Yes	Yes	Yes	No	No	34	31		50/75	90	50/100
19	57	No	No	Yes	Yes	Yes	7	18		90	75	100
20	60	No	Yes	No	Yes	Yes	26	23		100	90/90	
21	61	No	Yes	No	Yes	Yes	30	20		100	75/90	100
22	55	No	No	No	Yes	Yes	23	29		99	99	100
23	67	No	Yes	Yes	Yes	No	12	35		75/75	90	75
24	69	Yes	No	No	No	Yes	8	20		90	75	50/75
25	62	Unstable	No	No	No	Yes	7	31		90/90	90	90
26	67	No	Yes	Yes	Yes	No	18	22		75/90	50/75	90/75
27	68	No	Yes	Yes	Yes	No	10	33		100	75/75	50/75
28	70	No	No	No	Yes	Yes	17	27		90/90	99	75/100
29	73	Unstable	Yes	No	No	Yes	12	35		100	90	100
Mean ± SD	63 ± 8						17 ± 8	28 ± 4				

Coronary angiographic data are expressed as the number and percentage of stenosis severity. *Second number after slash indicates a second stenosis within this vessel.

CHF = congestive heart failure; EF = ejection fraction; LAD = left anterior descending coronary artery; LCx = left circumflex coronary artery; LMS = left main (coronary artery) stenosis; LVEDP = left ventricular end-diastolic pressure; MI = previous myocardial infarction; RCA = right coronary artery.

ential search of tracer maximum was employed to generate polar maps of relative tracer distributions. Nitrogen-13 ammonia uptake was compared to a normal database, and abnormalities were defined in terms of standard deviations (SD). If regional N-13 activity concentrations were within 2.5 SD of the normal distribution, a segment was considered to be normally perfused. Segments with this criterion and normal metabolism, but with impaired regional myocardial function, were categorized as NN myocardium. Because myocardial FDG uptake is barely influenced by blood flow and is primarily determined by the metabolic state of the patient, FDG uptake was normalized to a myocardial region with the highest N-13 ammonia uptake. This approach assumes that this segment represents the most normal tissue, which is selected as the metabolic reference. Relative FDG and N-13 ammonia uptakes were compared, and segments displaying >10% increased FDG uptake were identified as mismatch (MM), representing increased regional extraction of FDG (12). A match (M) was defined as NH_3 activity below −2.5 SD and the difference between NH_3 and FDG ≤10%, which was thought to reflect scarred myocardium. According to this viability criteria, the program determined the percentage of normal perfused myocardium (NN), of viable myocardium with mismatch (MM) and of scarred myocardium (M) for the entire LV and for each of the 13 anatomically defined ventricular segments.

Two-dimensional echocardiography. In all patients, two-dimensional echocardiography was performed one day before the operation and at 11 days, 14 weeks and about one year after revascularization. The images were recorded on a 12.5-mm VHS videotape. Regional wall motion and thickening in each segment were graded visually by two independent observers who had no knowledge of the PET findings, using a five-point scoring system: 3 = normal; 2 = hypokinesia; 1 = severe hypokinesia; 0 = akinesia; −1 = dyskinesia. Interobserver variability was determined by the Kappa statistic. The Kappa value was 0.87 preoperatively ($p < 0.01$), 0.81 at 11 days ($p < 0.01$), 0.84 at 14 weeks ($p < 0.01$) and 0.89 at 12 to 14 months after the operation ($p < 0.01$). In 96 segments of disagreement, consensus was obtained. Regional wall motion and thickening were evaluated at the chordal, papillary muscle and apical levels corresponding to the 13 anatomically defined PET segments. Improvement of contractile function was defined when functional score improved by one or more grade.

Data analysis. Of the 377 LV segments, 137 segments were excluded from data analysis. Septal areas were excluded owing to the frequent occurrence of paradoxic wall motion after coronary artery bypass graft surgery (CABG) (13,14). Other exclusion criteria included preoperative normal wall motion and segments with postoperative poor echocardiographic image quality (n = 31). All nonrevascularized segments were also excluded, but were analyzed separately to serve as a control group.

Statistical analysis. Results are presented as the mean value ± SD. Analysis of variance using a univariate general linear model with repeated measures was performed. The covariates were the different patients, nine different LV segments and the three PET classes (MM, NN and scar tissue). The wall motion score represented the dependent variable. The within-subject was the time course, including preoperative measurements and measurements after 10 days, 4 months and >12 months.

Logistic regression was used for comparison of the frequency of complete functional restoration between NN and MM myocardium. Associations between categoric data were evaluated using the chi-square test. All tests were performed two-sided. Interobserver variability was assessed by the Kappa statistic. A p value <0.05 was considered statistically significant.

RESULTS

Prevalence of flow–metabolism mismatch (MM), normal perfused but dysfunctioning myocardium (NN) and scar tissue (M) before revascularization. The following data represent 240 dysfunctional LV segments. The preoperative distribution according to NN myocardium, MM myocardium and scar tissue (M) is demonstrated in Table 2. Angiographically determined stenosis severity and the number of lesions were correlated with the degree of wall motion abnormalities. Segments that were supplied by vessels with no stenosis had a significantly higher wall motion score of 1.7 ± 0.7, as compared with 0.9 ± 0.7 for those segments supplied by arteries with one lesion ($p < 0.01$) or multiple lesions (0.5 ± 1.0) ($p < 0.03$). In addition, stenosis severity and the number of lesions were significantly more pronounced in scintigraphically determined scar tissue than in NN myocardium ($p < 0.04$). MM segments showed a tendency to be supplied by vessels with higher stenosis severity and multiple lesions, as compared to NN segments ($p = 0.07$).

Time course of functional recovery of all viable, dysfunctional segments. The following data represent the analysis of 224 preoperative viable segments, of 215 segments after 11 days, of 198 segments after 14 weeks and of 214 segments after 14 months. The reasons for this incomplete follow-up were limited postoperative image quality and refusal by some patients to undergo imaging.

Table 2 demonstrates the percentage and number of NN and MM segments according to the echocardiographic wall motion score at different time points. Figures 1 and 2 illustrate the functional changes for NN and MM segments over time. For both viable conditions, a significant improvement occurred after 11 days and 14 weeks. However, this significant improvement was not observed after 14 months, as shown in Figure 3. Although the extent of improvement between MM and NN segments was not significantly different, complete functional restoration was observed significantly more often in NN segments after 14 weeks than in

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Table 2. Percentage of NN and MM Segments According to the Echocardiographic Wall Motion Score (<3) at Different Time Points

	Preoperatively			11 Days			14 Weeks			14 Months		
WM Score	NN (n = 167)	MM (n = 57)	M (n = 16)	NN (n = 158)	MM (n = 57)	M (n = 16)	NN (n = 156)	MM (n = 42)	M (n = 16)	NN (n = 157)	MM (n = 57)	M (n = 16)
−1	1.8% (3)	8.8% (5)	25.0% (4)	0	5.3% (3)	6.2% (1)	0	2.4% (1)	6.2% (1)	0	1.8% (1)	12.5% (2)
0	16.2% (27)	43.9% (25)	31.2% (5)	2.5% (4)	3.5% (2)	37.5% (6)	1.3% (2)	7.1% (3)	37.5% (6)	1.3% (2)	10.5% (6)	31.2% (5)
1	61.7% (103)	40.4% (23)	43.7% (7)	26.6% (42)	45.6% (26)	56.2% (9)	19.2% (30)	23.8% (10)	50.0% (8)	18.5% (29)	17.5% (10)	50.0% (8)
2	20.4% (34)	7.0% (4)	0	58.9% (93)	42.1% (24)*	0	57.1% (89)	61.9% (26)	6.2% (1)	49.7% (78)	52.6% (30)	6.2% (1)
3	0	0	0	12% (19)	3.5% (2)†	0	22.4% (35)	4.8% (2)*	0	30.6% (48)	17.5% (10)†	0
Mean ± SD	1.01 ± 0.7	0.46 ± 0.8*	0.19 ± 0.8	1.80 ± 0.7	1.35 ± 0.8*	0.5 ± 0.6	2.01 ± 0.7	1.60 ± 0.8*	0.56 ± 0.7	2.10 ± 0.7	1.74 ± 0.9*	0.5 ± 0.8

*$p < 0.01$ versus NN segments. †$p < 0.05$ versus NN segments.
M = matched defect (scar tissue); MM = flow–metabolism mismatch; NN = normal perfused but dysfunctional myocardial segments; WM = wall motion; −1 = dyskinesia; 0 = akinesia; 1 = severe hypokinesia; 2 = hypokinesia; 3 = normal.

Figure 1. Functional changes for NN segments over time. Numbers of the segments are given and are related to the values before. ↑ = improvement by at least one wall motion score; ↔ = maintained function; ↓ = deterioration by at least one wall motion score.

MM segments (22.4% vs. 4.8%; $p < 0.01$). This significant difference was also present after 14 months (Table 2), although 19 NN segments versus 6 MM segments had a further deterioration in wall motion (Fig. 1 and 2).

Time course of functional recovery in viable segments with severe wall motion abnormalities. To determine whether complete functional recovery is different in segments that had severely depressed wall motion at baseline, preoperative hypokinetic segments (wall motion score 2) were excluded from the data analysis. As depicted in Figure 4, 14 weeks after the operation, 13.4% of the NN segments compared with 2.6% of the MM segments showed normal wall motion ($p < 0.04$), and 14 months after the operation, 27.2% of the NN segments demonstrated complete functional restoration, whereas only 13.2% of the MM segments displayed normal contractile function ($p < 0.05$). This significant difference may be attributed to the observation that 27.5% of NN segments had further improvement by one wall motion score, whereas only 10.3% of MM segments showed such an improvement after 14 months ($p < 0.03$). This difference suggests that the capacity of functional recovery in MM segments is limited and that further improvement does not occur.

Relative FDG accumulation in MM and NN myocardium in relation to functional recovery. NN segments with incomplete recovery showed normalized FDG activity of 84.5 ± 16.3%, whereas NN segments with complete restoration showed a tendency toward higher FDG activity of 88.3 ± 14.4% ($p = 0.13$). In contrast, a significant difference in FDG activity was found between NN segments with complete restoration (88.3 ± 14.4%) and MM seg-

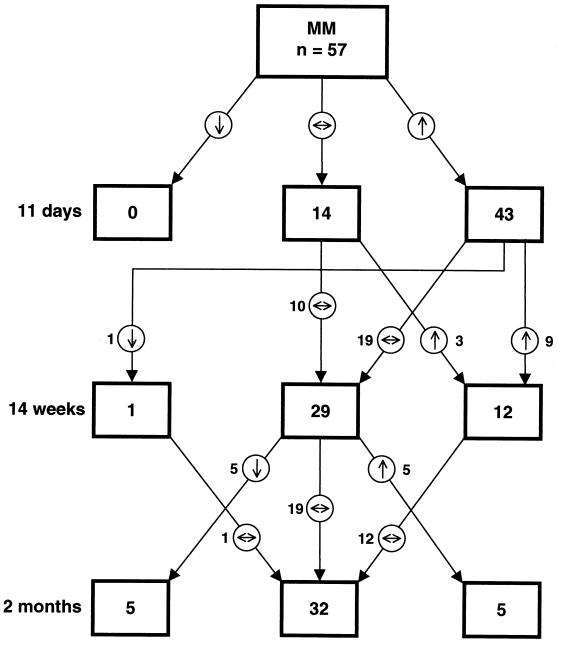

Figure 2. Functional changes for MM segments over time. Numbers of the segments are given and are related to the values before. ↑ = improvement by at least one wall motion score; ↔ = maintained function; ↓ = deterioration by at least one wall motion score.

ments with persisting WM abnormalities (81.6 ± 14%; $p < 0.01$). In addition, segments with preoperative normal wall motion had significantly lower FDG activity (77.8 ± 20%), compared with NN segments with complete functional restoration ($p < 0.03$).

Wall motion changes in scar tissue. The functional change in the mean wall motion score of the 16 segments defined as scar tissue is shown in Table 2. Absolute changes over time within this group are illustrated in Figure 3. No significant changes were observed during the time course.

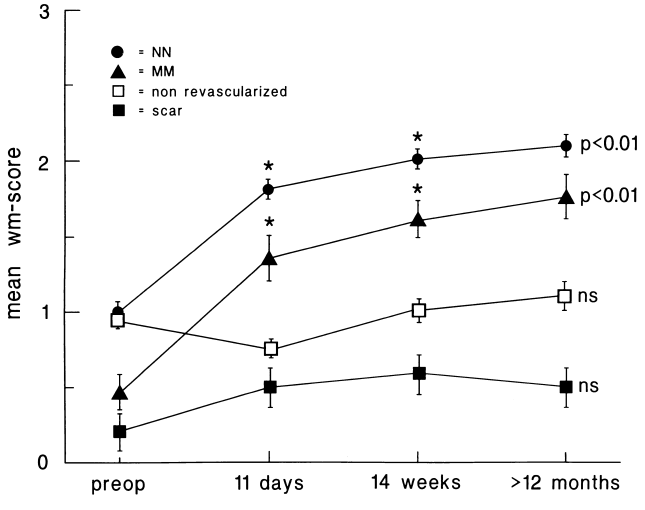

Figure 3. Functional improvement in mean wall motion (wm) scores of MM myocardium, NN myocardium and M myocardium (scar tissue) are expressed as the mean value ± SEM. In contrast to viable myocardium, only minor changes were seen for scar tissue (M). ns = not significant.

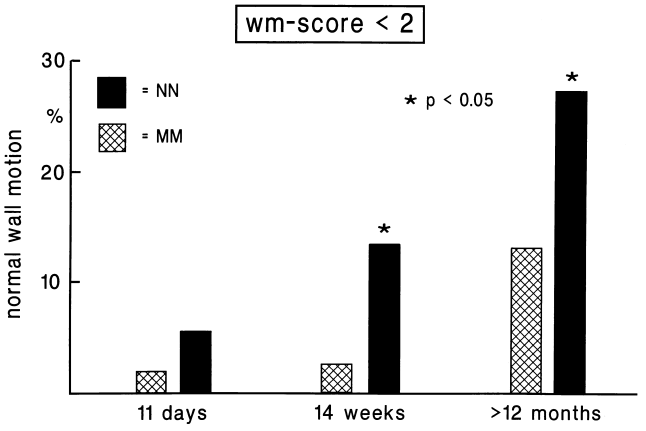

Figure 4. Time course and percentage of complete functional recovery of MM and NN segments with severe wall motion (wm) abnormalities preoperatively.

Wall motion changes in viable, nonrevascularized segments. Nonrevascularized segments (n = 26) were analyzed separately to serve as a control group. The mean wall motion score of these segments was 0.96 ± 0.66 preoperatively, 0.76 ± 1.14 at 11 days, 1.03 ± 1.07 at 14 weeks and 1.11 ± 1.10 after >12 months. Any significant improvement could not be observed. The negative predictive value for this separate analysis was 73%.

DISCUSSION

Prevalence of flow–metabolism mismatch (MM), normal perfused but dysfunctioning myocardium (NN) and scar tissue (M). In the present study, 23.8% of the segments showed a flow–metabolism mismatch pattern, 69.6% were identified as NN myocardium and only 6.7% were classified as scar tissue. However, we must emphasize that this small extent underrepresents the real extent of scar tissue within the LV. The exclusion of all septal areas and the categorization of segments according to the most representative scintigraphic entity within that segment explain the low prevalence. The total distribution of scar tissue for the entire study group was 11.3% (range 0% to 40%). Taking only the 18 patients with a confirmed previous myocardial infarction, the extent of scar tissue within the group would increase to 18.3% (range 6% to 40%).

Flow–metabolism mismatch areas were observed in almost 24% of all segments, which is in accordance with previous investigations in patients with LV dysfunction and heart failure symptoms (15). However, the majority of dysfunctional myocardial segments displayed the scintigraphic pattern of normal perfusion. Normal or near normal blood flow at rest to dysfunctional myocardial segments has been demonstrated by several investigators using either quantitative (7,8) or relative flow measurements by PET (5). Myocardial stunning as a consequence of repetitive episodes of ischemia may serve as a clinical explanation for the coexistence of normal blood flow at rest with impaired myocardial function. Although, in the present study, half of

the patients had a history of stable or unstable angina pectoris, clinical conditions in which myocardial stunning has been observed (16,17); the other half had symptoms of congestive heart failure. In these patients, any increase in oxygen demand due to normal daily activities can also lead to ischemia, and therefore to postischemic dysfunction. Thus, it is conceivable that either repetitive demand or supply-induced ischemia has led to regional myocardial dysfunction in the NN segments. The higher FDG activity within the NN segments with complete functional restoration, as compared with segments with preoperative normal wall motion, may represent an indication for the presence of ischemically compromised myocardium.

Besides confirming previous investigations reporting the coexistence of normal blood flow at rest with impaired systolic function (5,7–9), this study also showed that the majority of the dysfunctional myocardial segments have a scintigraphic pattern of normal perfusion. That this observation has not been addressed in earlier studies may be explained by the fact that only patients with advanced CAD, severe LV dysfunction and congestive heart failure were enrolled. It is conceivable that in this specific patient group, myocardial dysfunction is scintigraphically characterized by small relative differences in uptake of radiolabeled flow tracers at rest. With more severe CAD and hypoperfusion at rest, adaptive processes may be exhausted, leading to metabolic derangements. Therefore, it is possible that a continuing deleterious process from NN to MM segments exists, and that the mismatch pattern represents the limits of viability, as histologic studies suggest (18). In addition, previous prognostic studies indicate a higher incidence of clinical events in patients with a mismatch pattern, suggesting the instability of this process.

Time course of functional recovery and extent of improvement in flow–metabolism mismatch (MM) and normal perfused but dysfunctioning myocardium (NN). Most previous studies have reported data at only one point in time after CABG. Although Topol et al. (19) reported immediate improvement in regional wall thickening after CABG (19), most other investigators studied functional recovery after three to six months (5,7,20). At present, there are no sufficient data concerning the time course of recovery and the extent of improvement of previous ischemic areas. In the present study, >70% of MM and NN segments showed an improvement by at least one wall motion score after 11 days, confirming the early recovery of function observed by Topol et al. (19). This early improvement was also observed in the segments with severely impaired regional wall motion preoperatively, suggesting that the contractile reserve of these segments was not completely absent, and that the restoration of flow after adequate coronary revascularization may lead to partial recovery of function. As demonstrated in Figure 3, function of both viable conditions (MM and NN) improved in parallel; the only difference was that they were starting from different wall motion scores, suggesting different degrees of myocardial injury. Fourteen months after revascularization, the majority of the NN and MM segments did not show any further improvement, compared with the improvement achieved after 14 weeks, indicating that either complete functional recovery has already occurred or that a longer period may be required for structural repair processes. Histologic studies of hibernating myocardium, referred to as the "mismatch area" by PET imaging, have shown several morphologic alterations, including depletion of contractile filaments accompanied by cellular sequestration, glycogen accumulation and an increased degree of extracellular fibrosis. Schwarz et al. (18) have recently reported that, in hibernating myocardium, adaptive processes may be exhausted and that persistent hypoperfusion or the occurrence of multiple ischemic episodes may lead to progressive myocyte degeneration with apoptosis and fibrosis. In addition, it has been shown that patients with severe morphologic alterations showed incomplete functional restitution three months after revascularization, whereas more rapid clinical improvement was observed in patients with slight to moderate morphologic degeneration (20). In the present study, it was interesting to note that only 10.3% of MM segments versus 27.5% of NN segments improved by one wall motion score after one year ($p < 0.03$). Therefore, it is likely that the mismatch pattern in this study group represents a more advanced stage of cellular alterations. Furthermore, after initial partial recovery of function, further improvement may be determined by slow repair processes or structural remodeling. However, we must emphasize that in patients with advanced CAD and congestive heart failure, it is unlikely that complete functional recovery will occur after revascularization, because other factors, such as subendocardial infarction, LV remodeling or elevated myocardial wall stress, are important factors in the pathophysiology of persisting LV dysfunction. This may also explain the observation that only 31% of normal perfused myocardium regained complete functional restoration, and that in the majority of all segments, hypokinesia remained. However, even partial recovery of function at rest and decreased stress-induced ischemia in revascularized myocardium may contribute significantly to improved functional status and better survival.

Study limitations. In interpretating the results of this study, several limitations should be recognized. Semiquantitative myocardial blood flow estimates were employed to differentiate between chronically hypoperfused and normally perfused myocardium in association with regional LV dysfunction. Circumferential profile analysis detects regional heterogeneity of blood flow. Normal blood flow at rest has been defined by applying a statistical threshold (−2.5 SD) based on data obtained in healthy volunteers. This threshold includes a reduction of ~20% to 30% of regional tracer uptake as compared with "normal mean values," and thus is not sensitive to detect small reductions in blood flow. Previous studies using quantitative flow measurements have indicated small to moderate decrease in rest blood flow in hibernating myocardium (21). The

semiquantitative defenition of "normal flow" may therefore include areas with decreased flow. However, the diagnostic variables were optimized to detect scar tissue, using flow markers such as N-13 ammonia, and coincided with fixed thresholds of 50% to 60% of maximal activity employed for other tracer approaches (22). Previous work from our laboratory has demonstrated that semiquantitative flow estimates alone have only limited predictive value for functional recovery; the combination of flow and metabolic imaging by PET provides the best diagnostic accuracy (23). Regional comparison of N-13 and FDG activity allows identification of segments with increased glucose extraction (12), which is the hallmark of jeopadized myocardium. A regional difference of 10% tracer retention has been shown to provide the best predictive value of functional recovery. Second, regional LV function by ecchocardiography was evaluated visually by two different investigators. Although any qualitative assessment is subject to interobserver variability, the kappa statistic showed good correlation. Third, functional follow-up was not completed in all viable segments owing to limited postoperative image quality or withdrawal from the study protocol by the patients. However, at every time point, 88% to 96% of all segments were available for echocardiographic determination; therefore, it is unlikely that the segments that were not investigated would have significantly altered the results of this study. Finally, this study did not include angiographic follow-up studies. Although no patient had evidence of postoperative myocardial infarction and none had ongoing angina pectoris, we cannot rule out the possibility that graft closure or restenosis may have contributed to the incomplete functional recovery during the time course of observation.

Conclusions. In patients with advanced CAD, congestive heart failure and severe LV dysfunction, a preoperative scintigraphic pattern of normal perfusion associated with regional myocardial dysfunction is more prevalent than a flow–metabolism mismatch pattern. Mismatch areas were associated with more severe preoperative wall motion abnormalities and incomplete postoperative recovery, whereas in NN myocardium, the recovery to normal wall motion was significantly more frequent, even in segments with severely impaired myocardial function. Because of the fact that functional recovery is progressive over time, these data demonstrate that the most appropriate time for functional evaluation is after 14 weeks. However, for evaluation of complete functional recovery, waiting up to one year is recommended. Thus, these data suggest that different scintigraphic characteristics may represent different degrees of myocardial ischemic injury, and that areas with decreased N-13 ammonia uptake but maintained metabolic activity are those with the most incomplete and protracted recovery.

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