Improvement of Left Ventricular Ejection Fraction, Heart Failure Symptoms and Prognosis After Revascularization in Patients With Chronic Coronary Artery Disease and Viable Myocardium Detected by Dobutamine Stress Echocardiography

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OBJECTIVES This study was designed to address, in patients with severe ischemic left ventricular dysfunction, whether dobutamine stress echocardiography (DSE) can predict improvement of left ventricular ejection fraction (LVEF), functional status and long-term prognosis after revascularization.

BACKGROUND Dobutamine stress echocardiography can predict improvement of wall motion after revascularization. The relation between viability, improvement of function, improvement of heart failure symptoms and long-term prognosis has not been studied.

METHODS We studied 68 patients with DSE before revascularization; 62 patients underwent resting echocardiography/radionuclide ventriculography before and three months after revascularization. Long-term follow-up data (New York Heart Association [NYHA] functional class, Canadian Cardiovascular Society [CCS] classification and events) were acquired up to two years.

RESULTS Patients with ≥4 viable segments on DSE (group A, n = 22) improved in LVEF at three months (from 27 ± 6% to 33 ± 7%, p < 0.01), in NYHA functional class (from 3.2 ± 0.7 to 1.6 ± 0.5, p < 0.01) and in CCS classification (from 2.9 ± 0.3 to 1.2 ± 0.4, p < 0.01); in patients with <4 viable segments (group B, n = 40) LVEF and NYHA functional class did not improve, whereas CCS classification improved significantly (from 3.0 ± 0.8 to 1.3 ± 0.5, p < 0.01). A higher event rate was observed at long-term follow-up in group B versus group A (47% vs. 17%, p < 0.05).

CONCLUSIONS Patients with substantial viability on DSE demonstrated improvement in LVEF and NYHA functional class after revascularization; viability was also associated with a favorable prognosis after revascularization. (J Am Coll Cardiol 1999;34:163–9) © 1999 by the American College of Cardiology

Many studies have demonstrated the use of low dose dobutamine stress echocardiography (DSE) in the prediction of functional recovery after revascularization (1–8). In these studies, high sensitivity and specificity to predict functional outcome were reported. However, several aspects of the usefulness of DSE need further study. First, most studies have included patients with mild to moderate left ventricular (LV) dysfunction. Assessment of viable myocardium and prediction of functional recovery after revascularization, however, bears most clinical relevance in patients with severely depressed LV function, because these patients are exposed at high risk when undergoing revascularization (9,10). Second, most studies have focused on regional LV function instead of global LV function (whereas recovery of global LV function has the most clinical relevance). Third, studies exploring the relation between the amount of viable myocardium and the magnitude of improvement of LV ejection fraction (LVEF) are scarce, as pointed out recently by Rahimtoola (11); the exact amount of viable tissue needed to result in improvement of LVEF is not known.

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Manuscript received August 6, 1998; revised manuscript received February 4, 1999, accepted March 15, 1999.
For clinical patient management, this information would be extremely valuable. Fourth, no studies with DSE have focused on prediction of improvement of functional status (which may clinically be more relevant than improvement of LVEF). Finally, long-term follow-up studies of patients with and without viability are scarce for DSE. We have addressed these issues in the present study. A total of 76 patients with poor LV function (LVEF 35% or less) were screened; follow-up of global LV function was related to the presence of viability. The relation between the extent of viability and the magnitude of improvement of LVEF was assessed. Next, receiver operating characteristic (ROC) curve analysis was performed to identify a cutoff value of viable myocardium needed to result in improvement of LVEF after revascularization. Using this cutoff value to separate the patients into “viable and nonviable patients,” the influence of viability on improvement of functional status and long-term prognosis was evaluated.

METHODS

Patients, Study Protocol

Patients were eligible if they fulfilled the following inclusion criteria:

1. stable, chronic coronary artery disease;
2. depressed LV function on LV ventriculography (LVEF 35% or less);
3. already scheduled for revascularization (percutaneous transluminal coronary angioplasty/coronary artery bypass grafting [CABG]);
4. no significant valvular disease (patients with 3–4+ (moderate–severe) mitral insufficiency were excluded), and
5. adequate acoustic window to allow DSE.

The results of DSE did not influence the decision to revascularize. Within one month before revascularization radionuclide ventriculography (RNV), echocardiography and combined low–high dose DSE were performed. Three months after the revascularization, echocardiography and RNV were repeated. The protocol was approved by the local Medical Ethics Committee (ThoraxCenter Rotterdam) and each patient gave informed consent before the test was started.

Dobutamine Echocardiography

Beta-adrenergic blocking agents were withdrawn 36 h before DSE; other cardiac medications were continued. Low–high dose DSE (up 40 \( \mu \)g/kg/min with addition of 1 mg atropine if necessary) was performed as described previously (12). The interpretation of the DSE studies was performed by three experienced observers blinded to the clinical data. Good inter- and intraobserver agreement for the analysis of DSE was reported previously (92% and 94% respectively) (3). For analysis of echocardiograms a 16-segment model was used (13). Segmental wall motion/thickening was scored on a five-point scale: 1 = normal, 2 = mildly hypokinetic, 3 = severely hypokinetic, 4 = akinetic and 5 = dyskinetic. Wall thickening was primarily utilized for the classification, preempting the problem of postoperative paradoxical septal motion. To reduce the confounding effect of tethering, segmental wall thickening was analyzed frame by frame during the first half of systole. The studies were analyzed using the digitized rest, low and high dose dobutamine images, displayed in a quad-screen format and by reviewing the videotapes. Four different patterns were observed in the segments that were dysfunctional at baseline:

1. Biphasic response: improvement of wall motion during low dose (either at 5 or 10 \( \mu \)g) followed by worsening of wall motion during high dose dobutamine.
2. Sustained improvement: improvement at low or high dose dobutamine without deterioration of wall motion.
3. Worsening: deterioration of wall motion during either low or high dose dobutamine.
4. No change: absence of improvement or worsening during the entire test.

Dysfunctional segments were classified viable when they exhibited any of the patterns except for the “no change pattern.”

Assessment of Baseline Dysfunction and Functional Outcome

Regional LV function. Regional function was assessed by resting echocardiography before and three months after the intervention. A 16-segment model was used, and each segment was scored as described under the subheading “Dobutamine Echocardiography” (inter- and intraobserver agreement for assessing resting wall motion were 84% and 87% [3]). Improvement of regional function was considered when wall motion improved by one grade or more; improvement from dyskinesia to akinesia was not considered improvement.

Global LV function. Global function was assessed by RNV at rest (before and three months after revascularization) in 46 patients as described previously (2). In the remaining patients the LVEF, before and after the revascularization, was calculated by cross-sectional echocardiography utilizing the apical biplanar Simpson’s technique (13).
Each patient had the same technique to assess LVEF before and after the revascularization, to avoid comparison of LVEFs obtained by different techniques. Improvement of global function after revascularization was defined as an increase of LVEF ≥5%, as used previously (1,2,7,14).

Assessment of Functional Status and Long-Term Follow-up

Functional status was assessed according to the New York Heart Association (NYHA) criteria (for symptoms of heart failure) and according to the Canadian Cardiovascular Society (CCS) classification (for angina pectoris). In each patient, the functional status before and three months after revascularization was determined by interviews and physical examinations conducted by an investigator blinded to the DSE and LVEF data. The long-term follow-up was performed by chart review and telephone contact. Follow-up data (NYHA functional class, CCS classification and events) were acquired up to two years. Early events were as follows: in-hospital mortality/infarction and low output syndrome (diagnosed when high inotropic medication or intra-aortic balloon pumping were used to sustain adequate hemodynamic status [15]). Late events were as follows: cardiac death (defined by the hospital chart documenting arrhythmic death or death attributable to congestive heart failure, myocardial infarction or cardiac arrest), nonfatal myocardial infarction and congestive heart failure requiring hospitalization.

Statistical Analysis

Continuous data were expressed as mean ± SD and compared using the Student t test for paired and unpaired data when appropriate. Univariate analysis for categorical variables was performed using the chi-square test with Yates’ correction. The relation between the number of dysfunctional, viable segments on DSE and the magnitude of improvement of LVEF after the revascularization was determined by the Kruskal-Wallis test. The optimal number of viable segments on DSE (discriminating between patients with and without improvement of LVEF after revascularization) was determined by ROC curve analysis. The optimal cutoff value (number of segments) was defined as that providing the maximal sum of sensitivity/specificity. Sensitivity, specificity and positive and negative predictive values are based upon their standard definitions and presented with their 95% confidence intervals (CIs). According to this cutoff value (number of viable segments on DSE), the patients were divided into two groups (viable and nonviable patients). The event-free (for definition of events see above) survival of these two groups of patients was compared using Kaplan-Meier curves. Differences between event-free survival curves were tested with the log-rank chi-square statistic. For all tests, a p value <0.05 was considered significant.

RESULTS

Study population. A total of 76 patients were included in the study; eight patients had LV aneurysmectomy (n = 4) or absence of functional follow-up (n = 4). None of the remaining 68 patients had a myocardial infarction or an episode of unstable angina/heart failure requiring hospitalization before revascularization. Revascularization was established by CABG in 60 patients and by angioplasty in eight patients. Indications for revascularization were heart failure in 36 and angina pectoris in 32. There were 57 men with a mean age of 61 years (range 43 to 79). Sixty-five (96%) had a previous infarction (>3 months before the study), and 55 exhibited Q waves on the electrocardiogram (29 anterior, 19 inferior and 7 both). They had on average 2.5 ± 0.7 stenosed vessels. Ten patients had diabetes mellitus type II and 13 had systemic hypertension.

Six patients were not studied after revascularization because of perioperative infarction (n = 2)/death (n = 1) or in-hospital death (n = 3). Because no regional wall motion and LVEF were assessed after revascularization in these six patients, the comparison between baseline data and three-month follow-up data was limited to the remaining 62 patients; the indication for revascularization in the six excluded patients was heart failure in four and angina pectoris in two. For the long-term follow-up, however, all 68 patients were included. None of the patients was referred for heart transplantation after revascularization.

Baseline function versus functional outcome. A total of 992 segments were analyzed (in 62 patients), with 554 (56%) demonstrating abnormal wall motion. Twenty-three were not revascularized adequately (based upon review of the CABG/angioplasty reports), leaving 531 segments for the analysis. Baseline dysfunction included dyskinesia in 9 (2%) segments, akinesia in 214 (40%), severe hypokinesia in 108 (20%) and mild hypokinesia in 200 (38%) segments. Improvement of wall motion occurred in 141 (27%) segments, including 61 mild hypokinetic, 44 severe hypokinetic and 36 akinetic segments (p < 0.01 vs. [mild] hypokinetic segments). None of the dyskinetic segments improved in function. None of the nonrevascularized segments improved in function. Baseline LVEF ranged from 13% to 35%. In the entire group the LVEF did not improve significantly (28 ± 6% vs. 30 ± 7%, p = NS). The LVEFs before and after revascularization of the individual patients are demonstrated in Figure 1. Twenty-one patients improved ≥5% in LVEF after the revascularization (from 26 ± 7% to 34 ± 7%). Forty-one patients did not improve their LVEF ≥5% (29 ± 5% vs. 28 ± 5%).

Dobutamine echocardiography versus functional outcome. The distribution of the different responses in dysfunctional segments to low–high dose dobutamine is demonstrated in Figure 2. Dobutamine stress echocardiography had a sensitivity of 89% (125/141, 95% CI 84% to 94%) and a specificity of 74% (287/390, 95% CI 70% to 78%), with a positive predictive value of 55% (125/228, 95% CI 49% to 61%) and a negative predictive value of 95% (287/303, 95% CI 92% to 98%) to predict improvement of regional LV function. There was a significant relation between the
number of viable segments (per patient) on DSE and the magnitude of improvement in LVEF after revascularization: \( y = 1.37^* x - 2.04 \) (\( p < 0.001 \), \( r = 0.70 \), \( n = 62 \)). The number of scar segments was not significantly related to the change in LVEF.

The ROC curve analysis showed that the cutoff value of four dysfunctional but viable segments yielded the highest sensitivity/specificity (Fig. 3); 18 of 21 patients with an improvement of LVEF after the revascularization had \( \geq 4 \) viable segments, whereas only four patients with \( \leq 4 \) viable segments did not improve (\( p < 0.05 \)). Using this cutoff level, DSE had a sensitivity of 86% (95% CI 71% to 100%) and a specificity of 90% (95% CI 81% to 99%), with a negative predictive value of 93% (95% CI 85% to 100%) and a positive predictive value of 82% (95% CI 76% to 88%) to predict improvement of LVEF.

Accordingly, the patients were divided into two groups. Group A consisted of 22 patients (18 undergoing CABG, four undergoing angioplasty) with \( \geq 4 \) viable segments on DSE; group B consisted of 40 patients (36 undergoing CABG, four undergoing angioplasty) with \( < 4 \) viable segments (Table 1). In group A the LVEF increased significantly after revascularization; the NYHA functional class and the CCS classification also improved significantly. Of the 13 patients (12 undergoing CABG, one undergoing angioplasty) presenting with heart failure symptoms, 12 (92%, 11 undergoing CABG, one undergoing angioplasty) improved their NYHA functional class by one grade or more (Fig. 4). All patients (\( n = 9 \), six undergoing CABG, three undergoing angioplasty) presenting with angina pectoris improved their CCS classification by one grade or more. In group B the LVEF did not improve after revas-

![Figure 1](https://via.placeholder.com/150)

**Figure 1.** Scatter plot showing the individual LVEFs before and after revascularization. Improvement of LVEF occurred over the entire range of LVEFs. The solid line represents the line of identity. LVEF = left ventricular ejection fraction; post = after revascularization; pre = before revascularization. Triangles = improvers; octagons = nonimprovers.

![Figure 2](https://via.placeholder.com/150)

**Figure 2.** Pie chart demonstrating the distribution of the different responses during dobutamine stress echocardiography.

![Figure 3](https://via.placeholder.com/150)

**Figure 3.** Receiver operating characteristic curve analysis showing that the cutoff level of four dysfunctional but viable segments yielded the highest sensitivity/specificity to predict functional outcome on a patient basis.

**Table 1. Differences Between Patients With \( \geq 4 \) Viable Segments (Group A) and \( < 4 \) Viable Segments (Group B) on Dobutamine Stress Echocardiography**

<table>
<thead>
<tr>
<th></th>
<th>Group A (( n = 22 ))</th>
<th>Group B (( n = 40 ))</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>61 ± 9</td>
<td>62 ± 9</td>
<td>NS</td>
</tr>
<tr>
<td>Gender (M/F)</td>
<td>19/3</td>
<td>33/7</td>
<td>NS</td>
</tr>
<tr>
<td>Q-wave MI</td>
<td>13 (59%)</td>
<td>36 (90%)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>VD</td>
<td>2.5 ± 0.7</td>
<td>2.5 ± 0.7</td>
<td>NS</td>
</tr>
<tr>
<td>DM</td>
<td>1 (5%)</td>
<td>7 (18%)</td>
<td>NS</td>
</tr>
<tr>
<td>HT</td>
<td>6 (27%)</td>
<td>6 (15%)</td>
<td>NS</td>
</tr>
<tr>
<td>Clinical presentation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AP</td>
<td>9 (41%)</td>
<td>21 (52%)</td>
<td>NS</td>
</tr>
<tr>
<td>HF</td>
<td>13 (59%)</td>
<td>19 (48%)</td>
<td>NS</td>
</tr>
<tr>
<td>LVEF pre (%)</td>
<td>27 ± 6*</td>
<td>28 ± 5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>LVEF post (%)</td>
<td>33 ± 7</td>
<td>28 ± 5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>NYHA pre</td>
<td>3.2 ± 0.7*</td>
<td>3.1 ± 0.5</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>NYHA post</td>
<td>1.6 ± 0.5</td>
<td>2.8 ± 0.7</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>CCS pre</td>
<td>2.9 ± 0.3*</td>
<td>3.0 ± 0.8*</td>
<td>NS</td>
</tr>
<tr>
<td>CCS post</td>
<td>1.2 ± 0.4</td>
<td>1.3 ± 0.5</td>
<td>NS</td>
</tr>
</tbody>
</table>

*p < 0.01 pre- vs. postrevascularization values.

AP = angina pectoris; CCS = Canadian Cardiovascular Score; DM = diabetes mellitus; HF = heart failure; HT = systemic hypertension; LVEF = left ventricular ejection fraction; MI = myocardial infarction; NYHA = New York Heart Association; post = after revascularization; pre = before revascularization; VD = vessel disease.
cularization; the NYHA functional class remained unchanged, whereas the CCS classification improved significantly. Of the 19 patients (17 undergoing CABG, two undergoing angioplasty) presenting with heart failure symptoms, four (21%, all undergoing CABG) improved their NYHA functional class one grade or more (p < 0.05 vs. group A, Fig. 4). Of the 21 patients (19 undergoing CABG, two undergoing angioplasty) presenting with angina pectoris, 19 (90%, 17 undergoing CABG, two undergoing angioplasty) improved their CCS classification by one grade or more (p = NS vs. group A).

**Dobutamine echocardiography versus long-term follow-up.** The duration of follow-up was 18.7 ± 8.1 months. A total of 25 events occurred in 68 patients. The early events included four cardiac deaths, two nonfatal infarctions and four low output syndromes. The late events included two cardiac deaths, four nonfatal infarctions and nine episodes of congestive heart failure.

Five of the six patients who were excluded from the three-month follow-up analysis (see above) had <4 viable segments on DSE and were thus assigned to group B; the remaining patient had ≥4 viable segments and was assigned to group A. The distribution of events in groups A and B is shown in Table 2. The number of hard events was not significantly different between the two groups; the entire event rate however was significantly higher in group B as compared with group A (17% vs. 47%, p < 0.05) as evidenced by Kaplan-Meier analysis (p = 0.02 by log-rank test, see Fig. 5). After 12 months, the event-free survival was 87% (SE 7%) in group A and 71% (SE 7%) in group B. After 24 months, the event-free survival was 82% (SE 8%) in group A and 53% (SE 7%) in group B.

In group A, the NYHA functional class remained improved at two years (3.2 ± 0.7 vs. 1.6 ± 0.6, p < 0.01). The CCS classification also remained improved (2.9 ± 0.3 vs. 1.3 ± 0.4, p < 0.01). In group B, the NYHA functional class remained unchanged at 2 years (3.1 ± 0.5 vs. 2.9 ± 1.0, p = NS). The CCS classification remained improved (3.0 ± 0.8 vs. 1.4 ± 0.5, p < 0.01).

**DISCUSSION**

Dobutamine stress echocardiography showed a high sensitivity and specificity to predict improvement of regional LV function. The number of viable segments on DSE was linearly related to the magnitude of improvement of LVEF. The ROC curve analysis showed that the cutoff value of four dysfunctional but viable segments (25% of the LV) yielded the highest sensitivity/specificity to predict improvement of global LV function: 86% versus 90%. Patients with ≥4 viable segments showed improvement in heart failure symptoms and had a significantly lower event rate during 2-year follow-up (as compared with patients with <4 viable segments on DSE). Improvement of angina pectoris was not related to the presence or absence of viability, because the CCS score improved after revascularization in patients with and without substantial viability.

**Findings in the Present Study**

**Incidence of recovery.** In the present study, 27% of the dysfunctional segments improved after revascularization, in

**Table 2.** Events in Patients With ≥4 Viable Segments (Group A, n = 23) and <4 Viable Segments (Group B, n = 45) on Dobutamine Stress Echocardiography

<table>
<thead>
<tr>
<th>Event</th>
<th>Group A</th>
<th>Group B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac death</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Infarction</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Low output syndrome</td>
<td>0%</td>
<td>4%</td>
</tr>
<tr>
<td>Late events</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cardiac death</td>
<td>1%</td>
<td>2%</td>
</tr>
<tr>
<td>Infarction</td>
<td>1%</td>
<td>3%</td>
</tr>
<tr>
<td>Episode of heart failure</td>
<td>1%</td>
<td>8%</td>
</tr>
<tr>
<td>Total events</td>
<td>4%</td>
<td>21%</td>
</tr>
</tbody>
</table>

*p < 0.05 vs. group B.

**Figure 4.** Change in NYHA functional class in the two groups after revascularization. In group A (patients with ≥4 viable segments) mean NYHA functional class improved from 3.2 to 1.8. In group B (patients with <4 viable segments) the mean NYHA functional class remained unchanged (from 3.1 to 2.8). NYHA = New York Heart Association; post = after revascularization; pre = before revascularization.

**Figure 5.** Event-free survival curves of the patients in the two groups. The event rate was higher in group B (p = 0.02 vs. group A).
line with previous results (16). Improvement was observed more frequently in the segments with mild dyssynergy (hypokinesia or mild hypokinesia) as compared with the segments with more severe dyssynergy, as reported by others (3,8). The incidence of improvement of global LV function (34% of patients) was comparable to the incidence of regional improvement; the findings suggest that a substantial amount of hibernating myocardium occurs in approximately one third of the patients. Moreover, as depicted in Figure 1, improvement occurred over the entire range of LVEFs, emphasizing that improvement of LVEF is not limited to patients with relatively preserved LV function.

Relation between viability and recovery. In the present study, approximately 90% of the viable segments improved in function after the revascularization; almost 75% of the segments without viability did not improve. A comparable sensitivity with a somewhat lower specificity was presented by Meza et al. (17), who studied a similar cohort of patients. The imperfect diagnostic accuracy of both studies may be related to several factors: 1) longer follow-up is needed; 2) occurrence of periprocedural necrosis resulting in absence of recovery in viable segments, and 3) false positive responses to dobutamine caused by tethering or occurring in the presence of subendocardial scar (18). The lower specificity in the study by Meza et al. (17) may further be related to the subtle differences in study protocols and viability criteria used.

In contrast with the large number of studies that have evaluated the use of DSE to predict improvement of regional LV function (19), only few studies have focused on prediction of improvement of global LV function (8), and most studies have included patients with a mildly depressed LV function. This study provides data in a large group of patients, all with severely depressed LV function. On a global basis, ROC curve analysis showed that application of a cutoff level of $\geq 4$ viable segments on DSE (representing $\geq 25\%$ of the LV) yielded the highest diagnostic accuracy to predict improvement of LVEF (Fig. 3). Intraobserver and interobserver agreement for this cutoff level were determined in 30 patients and were 97%, and 93%, respectively. Using the four-segment cutoff level, a sensitivity of 86% and a specificity of 90% were obtained. Nagueh and coworkers (8) studied 18 patients and showed that all individuals with a significant improvement in LVEF after revascularization had $\geq 4$ viable segments on DSE. These findings imply that a substantial amount of viable myocardium needs to be present to establish improvement of global LV function after revascularization. Moreover, the magnitude of improvement of LVEF was linearly related to the number of viable segments on DSE. In contrast, the improvement of LVEF was not related to the number of scar segments.

Relation between viability and improvement of symptoms. In this study, the presence of viable myocardium was linked not only to improvement of function, but also to improvement of heart failure symptoms. The data demonstrate that patients with a substantial amount of viable myocardium ($\geq 25\%$ of the LV, group A) are likely to improve in heart failure symptoms. The results are in line with those reported by Di Carli et al. (20). The authors showed, by applying ROC curve analysis, that 18% viable myocardium best predicted improvement of heart failure symptoms. Clinically, improvement in the quality of life (reflected by a reduction in heart failure symptoms) may be more important than the improvement in LVEF, as pointed out recently by Bonow (21). Hence, the presence of substantial viability in patients presenting with heart failure may be an indication for revascularization, as indicated recently by Marwick (22) and Beller (23).

Of interest, 21% of the patients with $< 4$ viable segments (group B) also improved in heart failure symptoms (only one of these patients improved in LVEF after revascularization). This observation is in close agreement with data reported recently by Lombardo et al. (24) showing that 22% of the patients without substantial viability on DSE demonstrated improvement of heart failure symptoms. It is plausible that in these patients, the improvement of heart failure symptoms was related more to revascularization of regions with stress-inducible ischemia (leaving resting LVEF unchanged after revascularization) than to revascularization of hibernating myocardium (improving resting LVEF after revascularization). This phenomenon can be tested by performing low–high dose DSE before and after revascularization, as recently reported by Afridi et al. (25). Therefore, the LVEF during stress may be a more optimal end point after revascularization than the assessment of resting LVEF, as already suggested by Kaul (26). Further studies are needed to elucidate these issues.

Long-term follow-up. Overall survival independent of the viability status in patients with severely depressed LV function was good after revascularization, comparable to previous results (27). However, in group A, significantly fewer events occurred (17% vs. 47%). These data are in line with recent studies using nuclear imaging techniques (28) and DSE (29,30). Pagley et al. (28) studied 70 patients with chronic coronary artery disease and LVEF $< 40\%$ with thallium–201 scintigraphy before revascularization. The authors showed that patients without substantial viability had a very high event rate at long-term follow-up. These findings and our results indicate that viability assessment may be very useful in preoperative risk stratification. Moreover, Haas et al. (15) showed that significantly fewer events occurred in patients undergoing revascularization, when preoperative viability assessment (using F18-fluorodeoxyglucose and positron emission tomography) was performed. In addition to event-free survival benefit in patients with substantial viability, we also showed that symptoms of heart failure decreased in these patients and that the improvement in NYHA functional class was maintained during the two-year follow-up period.
Limitations

Several limitations of the current study need to be addressed. First, repeat angiography or some form of stress testing after the intervention was not performed, therefore we cannot ascertain adequate revascularization of all segments. Reocclusion may have prevented some viable segments from recovering and may have influenced the results. Second, functional follow-up was limited to three months, whereas longer follow-up may be necessary for some segments to improve function. Third, it has been questioned recently whether end points other than improvement of function after revascularization should be used to assess the clinical benefit of revascularization (21). In addition to improvement of heart failure symptoms, these end points include improvement of exercise capacity and the relation between viability and prevention of LV dilation and remodeling after revascularization. The relation between the presence of viability before the revascularization and these aspects needs further study.

Conclusions. In the present study, it has been demonstrated that the presence of substantial viability on DSE is associated with improvement in LVEF and heart failure symptoms after revascularization, and is accompanied by a favorable prognosis. Hence, viability testing by DSE may guide therapeutic management in patients with severely ischemic LV dysfunction.

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