JACC Vol. 28, No. 3
September 1996:558–64

Prediction of Recovery of Myocardial Dysfunction After Revascularization

Comparison of Fluorine-18 Fluorodeoxyglucose/Thallium-201 SPECT, Thallium-201 Stress–Reinjection SPECT and Dobutamine Echocardiography

JEROEN J. BAX, MD,* JAN H. CORNEL, MD,† FRANS C. VISSER, MD,
PAOLO M. FIORETTI, MD,† ARTHUR VAN LINGEN, PHD, AMBROOS E. M. REIJS, MSC,†
ERIC BOERSMA, MSC,† GERRIT J. J. TEULE, MD, CEES A. VISSER, MD, FACC

Amsterdam and Rotterdam, The Netherlands

Objectives. We compared three techniques to predict functional recovery after revascularization.

Background. Recently, fluorine-18 (F-18) fluorodeoxyglucose in combination with single-photon emission computed tomography (SPECT) has been proposed to identify viable myocardium. Thallium-201 reinjection and low dose dobutamine echocardiography are used routinely for this purpose.

Methods. Seventeen patients (mean [±SD] left ventricular ejection fraction 36 ± 11%) were studied. Regional and global ventricular function were evaluated before and 3 months after revascularization by echocardiography and radionuclide ventriculography, respectively. Myocardial F-18 fluorodeoxyglucose uptake (during hyperinsulinemic glucose clamping) was compared with rest perfusion assessed with early thallium-201 SPECT. On a separate day, low dose dobutamine echocardiography and post-stress thallium-201 reinjection SPECT were simultaneously performed.

Results. The sensitivities for F-18 fluorodeoxyglucose/thallium-201, thallium-201 reinjection and low dose dobutamine echocardiography to assess recovery were 89%, 93% and 85%, respectively; specificities were 77%, 43% and 63%, respectively. Stepwise logistic regression indicated that F-18 fluorodeoxyglucose/thallium-201 was the best predictor. In hypokinetic segments, the combination of F-18 fluorodeoxyglucose/thallium-201 and low dose dobutamine echocardiography was the best predictor. Global function improved (left ventricular ejection fraction increased >5%) in 6 patients and remained unchanged in 11. All three techniques correctly identified five of six patients with improvement. Fluorine-18 fluorodeoxyglucose/thallium-201 identified all patients without improvement; low dose dobutamine echocardiography identified 9 of 11 without improvement; and thallium-201 reinjection identified 6 of 11 patients without improvement.

Conclusions. Fluorine-18 fluorodeoxyglucose/thallium-201 SPECT was superior to the other techniques in assessing functional recovery. Integration of metabolic and functional data is necessary, particularly in hypokinesia, for optimal prediction of improvement of regional function.

(J Am Coll Cardiol 1996;28:558–64)

Identification of dysfunctional but viable myocardium, implicating potential reversibility of left ventricular function, is important in patients under consideration for revascularization (1). Metabolic imaging with fluorine-18 (F-18) fluorodeoxyglucose (2–6), thallium-201 reinjection scintigraphy (7–10) and low dose dobutamine echocardiography (11–14) have been proposed for the identification of viable myocardium.

Myocardial uptake of F-18 fluorodeoxyglucose is usually assessed with positron emission tomography (PET) (15). However, PET is not widely available. Several studies (16–20) have described the use of single-photon emission computed tomography (SPECT) in combination with F-18 fluorodeoxyglucose.

A direct comparison between F-18 fluorodeoxyglucose/thallium-201 SPECT and low dose dobutamine echocardiography and thallium-201 reinjection scintigraphy is lacking. In the present study, we compared the ability of the three techniques for predicting functional recovery in 17 patients undergoing surgical revascularization.

Methods

Patients. We studied 17 consecutive patients (14 men, 3 women; mean [±SD] age 57 ± 8 years, range 43 to 74) who were scheduled for revascularization on the basis of clinical and angiographic data and not on the results of the imaging studies. All 17 patients were symptomatic; 14 had angina pectoris; and 7 had dyspnea on effort. Patients had an average of 2.4 ± 0.8 stenosed coronary arteries. All patients had a history of chronic myocardial infarction (≥5 months before the study; Q wave in 11, non-Q wave in 6), and all had regional wall

From the Departments of Cardiology and Nuclear Medicine, Free University Hospital Amsterdam, Amsterdam; and †Department of Cardiology, Academic Hospital Rotterdam, Rotterdam, The Netherlands.

Manuscript received September 11, 1995; revised manuscript received April 3, 1996, accepted April 16, 1996.

*Present address: Department of Cardiology, Academic Hospital Leiden, Rijnsburgerweg 10, 2333 AA Leiden, The Netherlands.

Address for correspondence: Dr. Frans C. Visser, Department of Cardiology, Free University Hospital Amsterdam, De Boelelaan 1117, 1081 HV Amsterdam, The Netherlands.

Published by Elsevier Science Inc.

0735-1097/96/$15.00
PII S0735-1097(96)00222-7

motion abnormalities on rest echocardiography. Mean left ventricular ejection fraction was 36 ± 11% (range 18% to 64%; <35% in 9 patients), as assessed by left ventricular angiography. No patient had diabetes. All patients were clinically stable during the entire study period, and no patient experienced unstable angina or a myocardial infarction in the period between the imaging studies and revascularization. Medication included beta-adrenergic blocking agents (n = 11), angiotensin-converting enzyme inhibitors (n = 8), nitrates (n = 9), calcium antagonists (n = 6) and diuretic drugs (n = 5). Cardiac medication was continued during the studies, except for beta-blockers during low dose echocardiography.

Each patient gave informed consent to the study protocol, which was approved by the ethics committees of the participating hospitals.

Study protocol. All patients underwent one session of low dose dobutamine echocardiography and high dose dobutamine stress thallium-201 SPECT, followed by reinjection thallium-201 SPECT at the Academic Hospital Rotterdam. The F-18 fluorodeoxyglucose/thallium-201 SPECT study was performed within 2 weeks at the Free University Hospital Amsterdam. Regional and global function were evaluated by rest echocardiography and radionuclide ventriculography before and 3 months after operation.

Low dose dobutamine echocardiography. Low dose dobutamine echocardiography was performed as described previously (13). Briefly, a rest transthoracic echocardiogram was recorded in the standard views; dobutamine was infused intravenously, at doses of 5 and 10 μg/kg body weight per min, for 5 min at each dose. Echocardiograms were recorded on videotape during the last minute of each stage; the images were also digitized (on optical disk [Vingmed CFM 800]) and displayed side by side in quad-screen format to compare rest and dobutamine images with subsequent postoperative images. A three-lead electrocardiogram (ECG) was monitored continuously, and a 12-lead ECG was recorded every minute. Blood pressure was measured by sphygmomanometer at each 5-min stage.

Echocardiograms were reviewed by two observers (P.M.F., J.H.C.) who had no knowledge of the SPECT data. A 13-segment model was used (21); both inward wall motion and wall thickening were analyzed. Each segment was assigned a wall motion score from 0 to 3: *normal* = 0; *hypokinetic* = 1; *akinetic* = 2; and *dyskinetic* = 3. *Viable myocardium* was defined as systolic thickening (hypokinesia or normokinesia) in a segment that was akinetic or dyskinetic at rest or if normal wall motion was observed in segments that were hypokinetic at rest. The intraobserver and interobserver concordance of the response of wall motion during low dose dobutamine echocardiography has been reported previously (94% and 92%, respectively) (13).

Thallium-201 reinjection. Thallium-201 SPECT was performed after high dose dobutamine infusion (up to 40 mg/kg per min), as reported previously (13). Atropine (maximum 1 mg) was given when 85% of the maximal predicted heart rate was not reached. The patients reached on average 90% of the maximal predicted heart rate. At maximal stress, the rate-

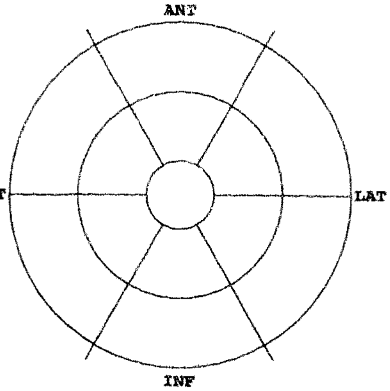

Figure 1. Schematic presentation of the 13-segment model used for the analysis of the SPECT and echocardiographic techniques. The myocardium was divided into one apical, six distal and six basal segments (anterior [ANT], anterolateral, inferolateral, inferior, inferoseptal and anteroseptal). INF = inferior; LAT = lateral; SEPT = septal.

pressure product was 19,140 ± 4,500 mm Hg × beats/min. Thallium-201 chloride (74 MBq) was administered intravenously 1 min before the end of the stress test. Post-stress imaging was started within 10 min after termination of the dobutamine infusion. Reinjection of thallium-201 (37 MBq) was performed 4 h after stress imaging; the reinjection images were acquired 20 min after reinjection. A Siemens Gammasonics single-head Rota Camera (Orbiter, Siemens Corp.) equipped with a low energy, all-purpose collimator was used. Imaging was performed over 180°, from the left posterior oblique to the right anterior oblique angles. Reconstruction of the transaxial slices yielded long- and short-axis projections perpendicular to the heart axis. For interpretation of both the stress and reinjection images, six short-axis, three vertical long-axis and three horizontal long-axis slices were used. Analysis was performed visually and semiquantitatively, using circumferential profiles. The myocardium was divided into the same 13 segments as those used for echocardiography (Fig. 1). Segmental thallium-201 uptake was scored from 0 = *normal* to 4 = *absent* activity. Segments were considered *partially reversible* when thallium-201 uptake improved (≥1 grade) without complete normalization on the reinjection images. Segments with complete normalization were considered *fully reversible*. A defect was considered *irreversibly fixed* when thallium-201 uptake did not improve on the reinjection images. The irreversible defects were classified into mild and severe, using circumferential profile analysis. A defect was classified *severe* if the thallium-201 uptake on the reinjection images was <50% of the activity of the normal segments (i.e., normal wall motion on echocardiography and highest thallium-201 uptake) and *mild* if the uptake was ≥50%. Viability was defined as *present* when segments showed normal or (partially) reversible or irreversible mild fixed uptake (10). Segments were classified *nonviable* in the presence of a severe fixed perfusion defect.

Fluorine-18 fluorodeoxyglucose/thallium-201. The F-18 fluorodeoxyglucose/thallium-201 SPECT study was performed as described previously (16). Myocardial F-18 fluorodeoxyglucose uptake was compared with regional perfusion measured with rest thallium-201 SPECT (images acquired within 15 min after tracer injection) (22). The F-18 fluorodeoxyglucose study was performed during hyperinsulinemic euglycemic clamping to standardize metabolic conditions (23) and to improve homogeneity of myocardial F-18 fluorodeoxyglucose uptake (24). Fluorine-18 fluorodeoxyglucose (185 MBq) was injected after 60 min of clamping; another 45 min was allowed for myocardial F-18 fluorodeoxyglucose uptake (25). Data acquisition was performed with a large field of view rotating dual-head gamma camera (ADAC Laboratories) equipped with special 511-keV collimators. The specific details of these collimators have been described elsewhere (26). Image acquisition was performed over 360°. Short-axis slices were obtained, and circumferential count profiles from F-18 fluorodeoxyglucose and early rest thallium-201 short-axis slices were generated by computer software. Fluorine-18 fluorodeoxyglucose and thallium-201 polar maps were then reconstructed and divided into the same 13 segments as those used for echocardiography (Fig. 1). A region of normal perfusion (defined as the area with the highest thallium-201 uptake associated with normal wall motion on the baseline echocardiogram) was drawn on the thallium-201 polar map. The activity of this area was normalized to the mean activity of the same area of a normal data base (obtained in normal subjects [17]), and the patient's polar map activities were adjusted to this value. For example, if the patient's thallium-201 activity was 80% in the selected normal region, and the corresponding activity in the normal data base was 85%, than all other activities on the patient's polar map were adjusted by a factor of 85/80.

The same region of normal perfusion was projected onto the patient's F-18 fluorodeoxyglucose polar map and compared with a normal data base for F-18 fluorodeoxyglucose SPECT and normalized in the same manner. A segment was considered as to have a *perfusion defect* when the thallium-201 activity was >2 SD below the normal reference value. *Myocardial viability* was defined by normal perfusion or by a 7% increase in F-18 fluorodeoxyglucose uptake in perfusion defects compared with that for thallium-201 activity. The cutoff value of a 7% increase in F-18 fluorodeoxyglucose uptake in perfusion defects has been established using receiver operating characteristic curve analysis of the level of increased F-18 fluorodeoxyglucose uptake in 44 patients undergoing revascularization (27).

Assessment of improvement of regional dyssynergy. A rest transthoracic echocardiogram was repeated 3 months after operation in all patients to assess functional recovery of the dyssynergic segments. We previously reported an intraobserver and interobserver agreement of 87% and 84%, respectively, for assessment of regional wall motion (13). Improvement after operation was considered present if preoperative hypokinetic segments were normokinetic or if segments that were akinetic or dyskinetic became hypokinetic or normokinetic. Wall thickening was primarily used for the classification of septal wall motion, thereby preventing the problem of paradoxic septal wall motion after surgical revascularization.

Only segments that were successfully revascularized were analyzed; this was based on a review of the surgical reports.

Assessment of improvement of global function. Radionuclide ventriculography was performed at rest with the patient in the supine position after the administration of 740 MBq of technetium-99m. Images were acquired with a small field of view gamma camera (Orbiter, Siemens Corp.) oriented in the 45° left anterior oblique position with a 5° to 10° caudal tilt. The left ventricular ejection fraction was calculated from the 45° left anterior oblique view by an automated technique. Improvement of global function after revascularization was defined as an increase of >5% in left ventricular ejection fraction.

Statistical analysis. All results are expressed as mean value ± SD. Sensitivity, specificity and positive and negative predictive values are based on standard definitions. Multivariable logistic regression was performed using the BMDP package to identify factors that were related to functional recovery after revascularization. A backward-stepwise algorithm was used with $p < 0.05$ (F test) to identify independent predictors. Variables included wall motion at baseline, low dose dobutamine echocardiography, thallium-201 reinjection SPECT and F-18 fluorodeoxyglucose/thallium-201 SPECT.

Results

Baseline characteristics. Of the 221 segments analyzed by echocardiography, 99 (45%) had abnormal wall motion before revascularization. The mean number of abnormal segments/patient was 6.0 ± 3.5; 60 segments were hypokinetic (61%), 36 akinetic (36%) and 3 dyskinetic (3%).

Detection of myocardial viability: agreement between three techniques. Agreement for the detection of viable and nonviable segments was 70% for F-18 fluorodeoxyglucose/thallium-201 and thallium-201 reinjection, 76% for low dose dobutamine echocardiography and thallium-201 reinjection and 80% for F-18 fluorodeoxyglucose/thallium-201 and low dose dobutamine echocardiography.

Prediction of functional recovery. Seven dyssynergic segments were not revascularized adequately, did not improve postoperatively and were excluded from further analysis. Thus, 92 segments were analyzed. Improvement of regional function after operation was observed in 27 segments (29%); 9 of 35 akinetic and 18 of 54 hypokinetic segments showed improvement, whereas no improvement occurred in the 3 dyskinetic segments.

Low dose dobutamine echocardiography showed signs of viable tissue in 47 dyssynergic segments (Fig. 2). This resulted in a sensitivity of 85% and a specificity of 63% for the detection of functional recovery (Fig. 3). The sensitivity and specificity for hypokinetic segments were 94% and 39% versus 67% and 93% for akinetic/dyskinetic segments, respectively. In patients with a left ventricular ejection fraction ≥35%, sensitivity and

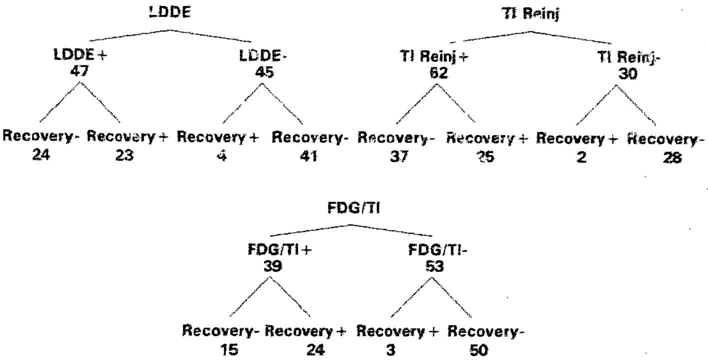

Figure 2. Schematic presentation of assessment of viability using the three techniques in successfully revascularized dyssynergic segments (n = 92) and the results at follow-up. FDG = fluorine-18 fluorodeoxyglucose; LDDE = low dose dobutamine echocardiography; Reinj = reinjection; Tl = thallium-201 SPECT; + = viable; − = nonviable.

specificity were 100% and 53%, in patients with a left ventricular ejection fraction <35%, these values were 70% and 67%.

Positive and negative predictive values are shown in Table 1. Although the negative predictive value was excellent for both hypokinetic and akinetic/dyskinetic segments, the positive predictive value was low for hypokinetic segments.

On *thallium-201 reinjection imaging*, 62 of the 92 dyssynergic segments were considered viable (Fig. 2), with an overall sensitivity and specificity of 93% and 43%, respectively (Fig. 3). The sensitivity and specificity for hypokinetic segments were 100% and 22% versus 78% and 69% for akinetic/dyskinetic segments. Sensitivity and specificity in patients with a left ventricular ejection fraction ≥35% were 100% and 21%; in patients with a left ventricular ejection fraction <35%, these values were 80% and 52%.

The negative predictive value was comparable to that for low dose dobutamine echocardiography (Table 1). However, the positive predictive value was low, independent of the severity of wall motion abnormalities or perfusion patterns.

On *F-18 fluorodeoxyglucose/thallium-201 SPECT*, 39 of 92 segments were viable (Fig. 2), for an overall sensitivity and specificity of 89% and 77%, respectively (Fig. 3). The sensitivity and specificity for hypokinetic segments were 94% and 67% versus 78% and 90% in akinetic/dyskinetic segments. In patients with a left ventricular ejection fraction ≥35%, the sensitivity and specificity were 100% and 74%; in patients with a left ventricular ejection fraction <35%, these values were 80% and 78%.

The negative predictive value was comparable to the other techniques. The positive predictive values were higher in the different subgroups than those for thallium-201 reinjection SPECT (Table 1).

A separate analysis excluding the 22 septal segments, thus avoiding inaccurate results due to abnormal septal wall motion after pericardiotomy, did not significantly change the aforementioned sensitivities and specificities of the three techniques. Univariable analysis of all segments revealed that the three techniques were predictive for functional recovery (Table 2). However, stepwise logistic regression showed that F-18 fluorodeoxyglucose/thallium-201 had the highest diagnostic value (Table 2); after this test, low dose dobutamine echocar-

Figure 3. Bar graph showing the sensitivities and specificities of the three techniques. Abbreviations as in Figure 2.

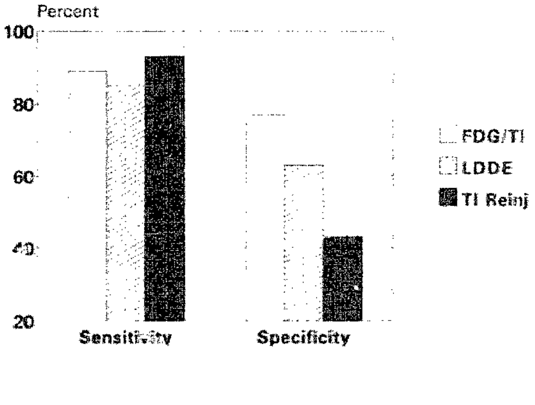

Table 1. Positive and Negative Predictive Values for Low Dose Dobutamine Echocardiography, Thallium-201 Reinjection SPECT and Fluorine-18 Fluorodeoxyglucose/Thallium-201 SPECT

	PPV (%)	NPV (%)
LDDE		
All segments	49	91
Hypokinetic segments	44	93
Akinetic segments	75	90
Tl-201 reinjection SPECT		
All segments	40	93
Hypokinetic segments	39	100
Akinetic segments	44	91
Normal perfusion	50	
Reversible defects	39	
Mild fixed defects	30	
Severe fixed defects		93
FDG/Tl-201 SPECT		
All segments	62	94
Hypokinetic segments	59	96
Akinetic segments	70	93
Normal perfusion	57	
Mismatch segments	69	
Match segments		94

FDG = fluorine-18 fluorodeoxyglucose; LDDE = low dose dobutamine echocardiography; NPV = negative predictive value; PPV = positive predictive value; Tl-201 = thallium-201; SPECT = single-photon emission computed tomography.

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Table 2. Univariable Analysis and Stepwise Logistic Regression Analysis of Three Diagnostic Techniques

	Univariable Analysis		Step 1	
	F Value	p Value	F Value	p Value
All segments				
FDG/Tl	53.4	< 0.001	24.9	< 0.001
Tl reinjection	12.3	< 0.001	0.0	0.88
LDDE	21.6	< 0.001	2.4	0.13
FDG/Tl and Tl reinjection	52.8	< 0.001	3.3	0.07
FDG/Tl and LDDE	41.8	< 0.001	1.0	0.33
Tl reinjection and LDDE	20.9	< 0.001	1.0	0.33
Akinesia/dyskinesia	1.0	0.67	1.3	0.42
Akinetic segments				
FDG/Tl	26.5	< 0.001	10.9	< 0.005
Tl reinjection	7.0	< 0.05	0.9	0.35
LDDE	22.9	< 0.001	4.6	< 0.05
FDG/Tl and Tl reinjection	22.9	< 0.001	0.4	0.51
FDG/Tl and LDDE	8.5	< 0.01	0.1	0.79
Tl reinjection and LDDE	21.1	< 0.001	3.5	0.07
Hypokinetic segments				
FDG/Tl	26.1	< 0.001	0.1	0.78
Tl reinjection	5.0	< 0.05	1.9	0.18
LDDE	7.3	< 0.01	0.8	0.38
FDG/Tl and Tl reinjection	29.7	< 0.001	1.0	0.32
FDG/Tl and LDDE	34.0	< 0.001	11.6	< 0.005
Tl reinjection and LDDE	8.4	< 0.01	0.1	0.79

Abbreviations as in Table 1.

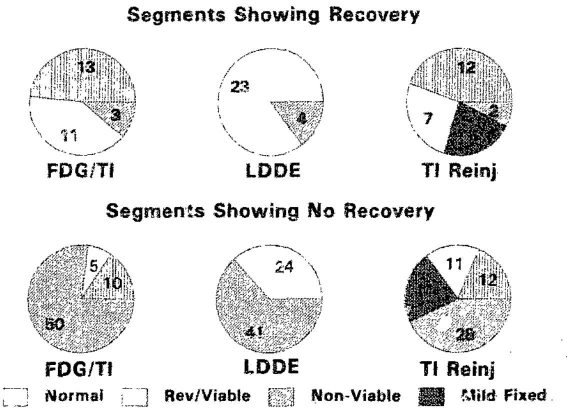

Figure 4. Pie charts comparing the proportion of viable or nonviable myocardial segments with fluorine-18 fluorodeoxyglucose/thallium-201 SPECT (FDG/Tl), low dose dobutamine echocardiography (LDDE) and thallium-201 reinjection (Tl Reinj) in relation to outcome after revascularization. Rev = reversible defects on thallium-201 reinjection.

diography and thallium-201 reinjection SPECT did not add significantly. For akinetic/dyskinetic segments, both F-18 fluorodeoxyglucose/thallium-201 and low dose dobutamine echocardiography and the combination of the F-18 fluorodeoxyglucose/thallium-201 SPECT and thallium-201 reinjection had similar values. For hypokinetic segments, the combination of F-18 fluorodeoxyglucose/thallium-201 SPECT with low dose dobutamine echocardiography had the highest value.

The different viability patterns of the three diagnostic methods are presented in Figure 4 according to functional outcome after revascularization. For the thallium-201 reinjection method, the mild fixed defect pattern had the lowest positive predictive value for recovery (30%), whereas normal perfusion had the best predictive value (50%). The normal perfusion pattern of F-18 fluorodeoxyglucose/thallium-201 SPECT had a similar positive predictive value. The mismatch pattern reached the highest positive predictive value (69%).

Effect of revascularization on global function. Left ventricular ejection fraction did not improve significantly in the entire group (36 ± 11% before vs. 39 ± 12% after operation); however, six patients showed a >5% improvement (from 31 ± 6% to 41 ± 7%). Using the presence of three or more viable segments/patient as a measure of substantial viability, all techniques correctly identified five of six patients with improved global function. Of the 11 patients with no improvement in global function, F-18 fluorodeoxyglucose/thallium-201, low dose dobutamine echocardiography and thallium-201 reinjection identified nonviable segments in 11, 9 and 6 patients, respectively.

Discussion

Myocardial viability is clinically relevant in patients with advanced left ventricular dysfunction who are being considered for revascularization (1). Dysfunction due to hibernation or (repetitive) stunning can be reversed after revascularization, whereas dysfunction due to scar is irreversible (1). The present study compared, in the same patients, the use of F-18 fluorodeoxyglucose/thallium-201 SPECT, low dose dobutamine echocardiography and thallium-201 reinjection SPECT for the prediction of improvement of regional contractile function after surgery. The main results of the present study can be summarized as follows: 1) All three techniques were able to identify patients with improved global function, whereas thallium-201 reinjection overestimated improvement of global function. 2) The three techniques had good sensitivity for detecting improvement of regional function after revascularization, but thallium-201 reinjection SPECT had poor specificity. 3) For akinetic/dyskinetic segments, the diagnostic values of low dose dobutamine echocardiography and F-18 fluorodeoxyglucose/thallium-201 SPECT were similar, in contrast to that for hypokinetic segments, where F-18 fluorodeoxyglucose was superior.

Fluorine-18 fluorodeoxyglucose/thallium-201 SPECT. Recently, F-18 fluorodeoxyglucose/thallium-201 SPECT has been introduced as an alternative method for F-18 fluorodeoxyglucose PET imaging (16–20). Burt et al. (19) and Martin et al. (20) demonstrated that myocardial F-18 fluorodeoxyglucose uptake measured with SPECT is in close agreement with F-18 fluorodeoxyglucose uptake assessed by PET. In the present study, a >5% improvement in ejection fraction was observed in patients with three or more viable segments on F-18 fluorodeoxyglucose/thallium-201 SPECT, whereas no improvement occurred in the patients with two or more viable segments. These findings confirm previous observations with F-18 fluorodeoxyglucose and PET (2,3) and indicate that a substantial amount of viable myocardium needs to be present to result in improved global left ventricular function.

We recently demonstrated the diagnostic value of F-18 fluorodeoxyglucose/thallium-201 SPECT for the detection of improvement of regional left ventricular function after revascularization (18,27); the findings in the current study are in agreement with the previous data.

Low dose dobutamine echocardiography. Low dose dobutamine echocardiography has been introduced as an effective method for the evaluation of myocardial viability. Our study demonstrates that low dose dobutamine is able to detect improvement of global function. Previous studies with low dose dobutamine addressed regional recovery after revascularization and reported sensitivities ranging from 74% to 92% and specificities ranging from 73% to 95% (11–14). The specificity of the present study (63%) is slightly lower than that for previous findings, but the sensitivity (85%) is well in line. In our study, specificity improved when only severely dyssynergic segments were evaluated, similar to previous studies focusing on patients with severe wall motion abnormalities (11,13).

Thallium-201 reinjection SPECT. On a per-patient basis, thallium-201 reinjection was able to identify those patients with improved global function but overestimated potential improvement. Although many studies have shown excellent detection of myocardial viability with thallium-201 reinjection imaging (7–10), its predictive value for improvement of regional function after revascularization varies considerably (7,8,13,28). Our study showed a high sensitivity (93%) but low specificity (43%), in contrast to that reported by Dilsizian et al. (7), but is in line with a recent study (13) involving patients with severely depressed left ventricular function (mean 31%).

Characteristics of viable segments. We found that all three techniques had a positive predictive value that was higher for akinetic/dyskinetic than hypokinetic segments. However, F-18 fluorodeoxyglucose/thallium-201 had a higher positive predictive value than low dose dobutamine echocardiography for hypokinetic segments. These segments are likely to have contained a mixture of normal myocardium, subendocardial necrosis and viable but jeopardized myocardium (Fig. 5). If relatively little viable but jeopardized tissue is present, F-18 fluorodeoxyglucose/thallium-201 will recognize this segment as nonviable. During dobutamine stimulation, however, the normal myocardium in these segments may become hyperkinetic, resulting in a false-positive response to dobutamine. If, however, in addition to normal and necrotic tissue, a substantial amount of viable but jeopardized tissue is present, both F-18 fluorodeoxyglucose/thallium-201 and low dose dobutamine echocardiography will recognize this tissue as viable, and improvement is likely to occur after revascularization.

The low specificity of thallium-201 reinjection for detecting functional recovery after revascularization has been previously explained by detection of islands of viable tissue of inadequate size, by tethering of adjacent scar tissue, by embalmed myocardium (29) and by nontransmural necrosis (13). All these factors may also be applicable to F-18 fluorodeoxyglucose/thallium-201; nevertheless, the specificity of F-18 fluorodeoxyglucose/thallium-201 for all segments was 77% versus 43% for thallium-201 reinjection. This indicates overestimation of prediction of recovery by thallium-201 reinjection imaging. Our results show that both reversible and mild fixed defects are responsible for this overestimation. Because we used a stress protocol we apparently were not able to separate viable/jeopardized myocardium from stress-induced ischemia. Also, a mild fixed defect may represent an area containing nontransmural scar that is unable to improve in function after revascularization.

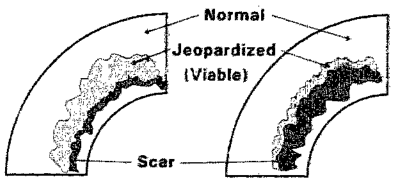

Figure 5. Illustration demonstrating the relative contribution of normal, scar and viable but jeopardized tissue to test results and functional outcome after revascularization in a hypokinetic segment. When a substantial amount of viable but jeopardized tissue is present **(left)**, both tests will demonstrate viable tissue, and recovery may occur after revascularization. When a mixture of predominantly normal and scar tissue is present **(right)**, no recovery of function will occur after revascularization. Fluorine-18 fluorodeoxyglucose (FDG)/thallium-201 will not show a mismatch pattern. However, low dose dobutamine (LDDE) infusion will recruit the normal myocardium, resulting in a false-positive response.

Study limitations. Several limitations of the present study need to be addressed. We did not perform repeat angiography after operation to assess graft patency; graft occlusion may have prohibited recovery of function.

Echocardiography was repeated 3 months after revascularization; this period may be too short to allow complete recovery of all dyssynergic but viable segments (29). Nonetheless, these features would affect all three techniques, thereby not changing the relative sensitivities and specificities of the techniques.

A recent study by Afridi et al. (12) has demonstrated that improvement of wall motion during low dose dobutamine infusion, followed by worsening during high dose dobutamine infusion, may provide the most accurate information in the assessment of functional recovery. We assessed wall motion only during low dose dobutamine infusion, which may have resulted in a somewhat lower diagnostic accuracy for the assessment of functional recovery.

Furthermore, the analytic correlation between echocardiographic segments, SPECT segments, anatomy and vascular territories is not known precisely. However, we used the same 13-segment model for both echocardiographic and SPECT studies, thereby reducing misalignment between both imaging modalities. Moreover, the American Society of Echocardiography has assigned specific echocardiographic segments to each vascular territory (30). In addition, Edwards et al. (31) have emphasized the good correlation between echocardiographic segments and coronary artery distribution.

In the present study, we reported the diagnostic accuracy of the three techniques in assessing improvement of both regional and global ventricular function. For the individual patient, improvement of global function is more important than improvement of regional function. Moreover, the segments within one patient are not independent, possibly influencing the results. However, no studies are currently available comparing these three techniques in the prediction of improvement of global function. To allow comparison with published reports, we included the diagnostic accuracy of the three techniques for the prediction of improvement of regional function.

Finally, only a small number of patients were studied; larger studies are needed to confirm our findings.

Conclusions. In patients with chronic left ventricular dysfunction, F-18 fluorodeoxyglucose/thallium-201 SPECT is superior to low dose dobutamine echocardiography and thallium-201 reinjection SPECT for the detection of regional functional recovery after revascularization. However, in akinetic segments, the accuracy of F-18 fluorodeoxyglucose/thallium-201 SPECT and low dose dobutamine echocardiography are comparable. Both techniques also provided similar information on a per-patient basis. Thallium-201 reinjection SPECT seems to overestimate both regional and global improvement after revascularization.

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