Ischemically compromised myocardium displays different time-courses of functional recovery: correlation with morphological alterations?

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Abstract

\textbf{Objective}: It has been demonstrated that positron emission tomography (PET) predicts the functional recovery of viable but ischemically compromised myocardium. Reversible contractile dysfunction after revascularization has been reported for ‘hibernating myocardium’ and stunned myocardium, however, there are little data concerning the time-course and the extent of improvement of the two different pathophysiological conditions.

\textbf{Methods}: Twenty-nine patients with advanced coronary artery disease and severely reduced left ventricular function (EF 18–35%) who were referred for isolated coronary artery bypass grafting underwent preoperative PET viability assessment and were functionally assessed by two-dimensional echocardiography preoperatively at 11 days, 14 weeks, and more than 12 months after surgical revascularization. Intraoperative biopsies were taken from dysfunctional areas defined by PET as segments of normal perfusion and normal metabolism (stunned myocardium) and from areas with a ‘mismatch’ between perfusion and metabolism (hibernating myocardium). The degree of morphological alterations was evaluated by electron microscopy. \textbf{Results}: In 70% of the 240 dysfunctional segments, ‘stunned myocardium’ was present whereas ‘hibernating myocardium’ could be detected in only 24% ($P = 0.01$). Hibernating myocardium was associated with more severe preoperative wall motion abnormalities and incomplete postoperative recovery. After 1 year, 31% of ‘stunned’ segments vs. only 18% of ‘hibernating’ segments showed complete functional restoration ($P < 0.05$). This incomplete improvement was associated with more severe morphological alterations including depletion of sarcomeres, accumulation of glycogen, loss of sarcoplasmatic reticulum, and cellular sequestration. \textbf{Conclusions}: These data indicate that in patients with severe ischemic left ventricular dysfunction ‘stunned myocardium’ is more prevalent than ‘hibernation’. Functional normalization is more frequent in ‘stunned’ segments, whereas areas of ‘hibernation’ showed more severe tissue injury and protracted recovery. Different degrees of myocardial injury coexist in most patients, which determines the time-course and the extent of improvement after revascularization. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Severe left ventricular dysfunction; Myocardial viability; Positron emission tomography; Functional improvement; Morphological alterations; Electron microscopy

1. Introduction

It is well established that ischemically compromised myocardium is associated with severe impairment of contractile function and worsening of heart failure [1,2]. However, in contrast to infarcted or scar tissue, dysfunctioning but viable myocardium has the potential to regain contractile function [1,3,4]. Positron emission tomography (PET) has been reported to be highly specific in distinguish-
‘stunned myocardium’ within the entire left ventricle in patients with severe left ventricular dysfunction. Furthermore, there are little data concerning the time-course and extent of improvement of dysfunctioning myocardium in relation to scintigraphic pattern and morphological alterations. Thus, this study evaluated the prevalence, the time-course of recovery, and the extent of improvement in segments of ‘hibernating myocardium’ as well as in segments of ‘stunned myocardium’. In contrast to the original definitions of ‘stunned myocardium’ and ‘hibernating myocardium’, this study defined stunning and hibernation according to PET viability criteria. Semiquantitative myocardial blood flow estimates were employed to differentiate between chronically hypoperfused (flow–metabolism mismatch) and normally perfused myocardium (stunned myocardium) in association with regional left ventricular dysfunction. Electron microscopy was used to test the hypothesis that chronic hypoperfusion is associated with a more advanced stage of cellular alterations.

2. Methods

2.1. Study population

Twenty-nine consecutive patients (27 men and two women) with advanced three-vessel CAD and severe left ventricular dysfunction, (EF \( \leq 0.35 \)), who were referred for isolated coronary artery bypass grafting (CABG) to our institution, were included in this study. All patients gave written informed consent and the study was approved by the Institutional Ethics Committee on Human Research. Table 1 shows the preoperative clinical and hemodynamic characteristics.

2.2. Coronary angiography

In all patients, cardiac catheterization was performed to assess left ventricular function and the extent of coronary artery disease. Advanced three-vessel disease was defined by experienced cardiologists as a visually estimated luminal narrowing of at least 75% of the diameter in each of the three major vessels or their major branches. None of the patients experienced an acute myocardial infarct between cardiac catheterization and CABG; however, three patients had symptoms of unstable angina.

2.3. Positron emission tomography

All patients underwent PET imaging with N-13 ammonia and 18-F fluorodeoxyglucose (FDG) at a mean of 23 ± 30 days before surgery (median 8 days). After initial transmission scanning for attenuation correction, resting regional myocardial perfusion imaging with N-13 ammonia (740 MBq) was performed. After waiting period of 40 min to allow sufficient N-13 decay, FDG (370 MBq) was injected and data acquisition was initiated 40 min after tracer injection for sufficient equilibrium conditions of the FDG distribution. Transaxial planes were obtained using a whole-body positron emission tomograph (Siemens CTI 951 or Siemens Exact 47). Attenuation-corrected transaxial emission images were generated from N-13 ammonia and FDG data.

2.4. Image analysis

Automated semiquantitative image analysis was employed using a radial three-dimensional maximum activity search based on interactive definition of the ventricular long axis with a cardiac analysis program (Munich Heart) developed in our institution [12]. Relative tracer distributions were displayed in polar map format. N-13 ammonia abnormalities were defined as standard deviations from a normal database, while FDG uptake was normalized to the region of maximum NH3 uptake. 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, however, with impaired wall motion were categorized to ‘stunned myocardium’. A ‘flow–metabolism mismatch’ (hibernating myocardium) was identified if NH3 activity was below −2.5 SD but the difference of FDG and NH3 exceeded 10%. Scar tissue was defined as NH3 activity below −2.5 SD and the difference of NH3 and FDG was ≤10%. According to this viability criteria, the program determined the percentage of normal perfused myocardium, viable with mismatch, and scarred myocardium for the entire left ventricle and for each of the 13 anatomically defined segments (Fig. 1).

2.5. Two-dimensional echocardiography

In all patients, two dimensional echocardiography was acquired 1 day before operation and at 11 days, 14 weeks, and more than 12 months after revascularization. Regional wall motion and thickening in each segment were graded visually by two independent observers, who were unaware of the PET findings, using a five-point scoring system (3 = normal, 2 = hypokinesia, 1 = severe hypokinesia, 0 = akinesia, −1 = dyskinesia). Regional wall motion and

| Table 1 |
| Preoperative clinical and hemodynamic characteristics (n = 29) |
|-----------------|-----------------|
| Age             | 63 ± 8 years    |
| EF\(^a\)         | 28 ± 4%         |
| LvedP\(^b\)      | 17 ± 8 mmHg     |
| Previous MI\(^c\)| 62%             |
| Angina pectoris   | 52%             |
| NYHA III + IV    | 82%             |
| CHF\(^d\)        | 55%             |
| Hypertension     | 52%             |
| Diabetes mellitus| 31%             |

\(^a\) EF, ejection fraction.  
\(^b\) LvedP, left ventricular enddiastolic pressure.  
\(^c\) MI, myocardial infarction.  
\(^d\) CHF, congestive heart failure.
thickening were evaluated at the chordal, papillary muscle, and apical levels corresponding to the 13 anatomically defined PET segments (Fig. 1). Improvement of contractile function was defined when functional score improved $\geq 1$ grade. Septal areas, all non-revascularized segments, segments with preoperative normal wall motion, and segments with postoperative poor image quality were excluded from data analysis.

2.6. Microscopic examination

At surgery, two transmural biopsies were taken with a Tru-Cut biopsy needle (Travenol Laboratories) when the patients were on cardiopulmonary bypass but before cardioplegic arrest. Biopsies were taken from dysfunctional segments of normal perfusion and normal metabolism (stunned myocardium), and from segments with a ‘mismatch’ (hibernating myocardium) between perfusion and metabolism (Fig. 1). The specimens were immediately fixed in 3% glutaraldehyde in cacodylate buffer, postfixed in chrome-osmium, dehydrated in graded series of ethanol, and routinely embedded in epon. Ultrathin sections were examined with a Zeiss EM 100R electron microscope after staining with uranyl acetate and lead citrate from areas showing the most progressive myocyte degeneration on semithick sections of each biopsy. No attempt was made to quantify the degree of subcellular myocardial degeneration.

2.7. Statistical analysis

The results are presented as mean values with standard deviations. An analysis of variance using an univariate general linear model with repeated measures was performed. Covariates were the different patients, nine different LV-segments, and the three PET-classes (hibernating myocardium, stunned myocardium, scar tissue). The wall motion score represented the dependent variable. The within-subject was the time-course including preoperative measurements, measurements after 11 days, 14 weeks, and after more than 12 months.

Logistic regression was used for comparison of the frequency of complete functional restoration between hibernating and stunned myocardium. Associations between categorical 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.

3. Results

3.1. Study population

All patients underwent successful revascularization with $3.6 \pm 0.7$ (range 2–5) venous or internal mammary artery bypass grafts without any other surgical procedures. No
patient had evidence of perioperative and postoperative myocardial infarction and none had ongoing angina pectoris during follow-up.

3.2. Prevalence of flow–metabolism mismatch (hibernating myocardium), normal perfused but dysfuntioning myocardium (stunned myocardium), and scar tissue before revascularization

Table 2 illustrates the percentage and number of stunned segments, hibernating segments, and scar tissue according to the echocardiographic WM-score preoperatively and at three different time points postoperatively.

Of the 377 left ventricular segments, 137 segments were excluded from data analysis due to the previously mentioned exclusion criteria. Therefore, the following data were obtained from 240 dysfunctional left ventricular segments. Fifty-seven segments (23.8%) demonstrated a perfusion–metabolism mismatch (HIB) with a mean wall motion score of 0.46 ± 0.8 (median: 0). Scintigraphic pattern of ‘stunned myocardium’ (STU) was present in 167 segments (69.6%) with a significantly higher mean wall motion score of 1.01 ± 0.7 (median: 1) (P < 0.01) indicating severe hypokinesis vs. nearly akinesis in hibernating segments (HIB). Only 16 segments (6.7%) were assigned to scar tissue with a mean score of 0.19 ± 0.8 (median: 0), which was not significantly lower than that of hibernating myocardium segments (P = 0.27).

3.3. Time-course of functional recovery of all viable, dysfunctional segments

The following data represent the analysis of 224 preoperative viable segments, 215 segments after 11 days, 198 segments after 14 weeks, and 214 segments after 14 months. The reasons for this incomplete segmental analysis were limited postoperative image quality and refusal by some patients to undergo imaging.

Eleven days after surgery stunned myocardium-segments showed an improvement in 108 segments, 50 segments remained unchanged, and none decreased (P < 0.01). Hypokinesis was already present in 58.9% and normal wall motion in 12%. Of the hibernating myocardium-segments, 43 showed an improvement, 13 remained unchanged, and one segment decreased (P < 0.01). Although this group also showed significant improvement, significantly less segments were assigned to hypokinesis (P < 0.01) or normal wall motion (P < 0.05). The extent of improvement between the two groups was not significantly different.

Fourteen weeks after surgery, 79.5% of the stunned myocardium-segments and 66.7% of the hibernating myocardium-segments were assigned to hypokinesis or normal wall motion, which were significantly different (P < 0.01). During this time interval, only four stunned myocardium-segments and one hibernating myocardium-segment showed a decrease in WM-score. Although the extent of improvement between hibernating myocardium and stunned myocardium was not significantly different, complete functional restoration in stunned myocardium-segments was observed significantly more often than in hibernating myocardium-segments (22.4% vs. 4.8%; P < 0.01). This significant difference was also present after >12 months (Table 2), although 19 stunned myocardium-segments vs. five hibernating myocardium-segments had a further decrease in wall motion.

3.4. Time-course of functional recovery in viable segments with severe wall motion abnormalities

To determine whether functional recovery is different between myocardial segments of stunned myocardium and those of hibernating myocardium, which had severely depressed wall motion, preoperative hypokinesis segments (WM-score 2) were excluded from data analysis. Therefore, from the 186 viable segments analyzed, 53 segments were assigned as hibernating myocardium, and 133 segments as

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**Table 2**

Percentage of STU- and HIB-segments according to the echocardiographic WM-score (WM-score < 3) at different time points

<table>
<thead>
<tr>
<th>WM-score</th>
<th>Pre-op</th>
<th>11 days</th>
<th>14 weeks</th>
<th>&gt; 12 months</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>STU²</td>
<td>HIB²</td>
<td>Scar</td>
<td>STU²</td>
</tr>
<tr>
<td>−1</td>
<td>1.8% (3)</td>
<td>8.8% (5)</td>
<td>25.0% (4)</td>
<td>5.3% (3)</td>
</tr>
<tr>
<td>0</td>
<td>16.2% (27)</td>
<td>43.9% (25)</td>
<td>31.2% (5)</td>
<td>2.5% (4)</td>
</tr>
<tr>
<td>1</td>
<td>61.7% (103)</td>
<td>40.4% (23)</td>
<td>43.7% (7)</td>
<td>26.6% (42)</td>
</tr>
<tr>
<td>2</td>
<td>20.4% (34)</td>
<td>7.0% (4)</td>
<td>0</td>
<td>58.9% (93)</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.0% (19)</td>
</tr>
</tbody>
</table>

Mean WM-score

| Total n | 167 | 57 | 158 | 57 | 16 | 156 | 42 | 16 | 157 | 57 | 16 |

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a * HIB vs. STU, P < 0.01; ** HIB vs. STU, P < 0.05.

b WM-score, wall motion score: −1, dyskinesis; 0, akinesis; 1, severe hypokinesis; 2, hypokinesis; 3, normal.

c Pre-op, preoperatively.

d STU, ‘stunned myocardium’ (normal perfused but dysfunctional myocardial segments).

e HIB, ‘hibernating myocardium’ (flow–metabolism mismatch).
stunned myocardium. As depicted in Fig. 2, 11 days after surgery there was no significant difference between the number of segments which showed complete functional restoration \( (P = 0.28) \). However, 14 weeks after surgery, already 13.4% of the stunned myocardium-segments vs. 2.6% of the hibernating myocardium-segments showed normal wall motion \( (P < 0.05) \), and more than 12 months after surgery, 27.2% of the stunned myocardium-segments represented complete functional restoration, whereas only 13.2% of the hibernating myocardium-segments displayed normal contractile function \( (P < 0.04) \). This significant difference may be attributed to the observation that 27.5% of stunned myocardium-segments improved further by one WM-score; whereas only 10.3% of hibernating myocardium-segments showed such an improvement after 14 months \( (P < 0.03) \).

3.5. Electron microscopy

At the ultrastructural level, all biopsy specimens showed signs of degeneration. There was no evidence for previous transmural myocardial infarction. Stunned myocardial cells showed mainly the appearance of normal or slightly degenerated myocytes with regularly distributed sarcomeres and rows of mitochondria tightly packed in between (Fig. 3). Beginning of degeneration, such as slight depletion of myofilaments in the perinuclear region and the occurrence of glycogen and non-specific cytoplasm was present (Fig. 4). Only a few cells showed more extensive cellular alterations, such as marked loss of myofibrils, which were replaced by large areas of glycogen and non-specific cytoplasm and the occurrence of numerous small mitochondria (Fig. 5).

However, biopsies of hibernating myocardium showed severe subcellular defects in virtually all cells. The most prominent ultrastructural change was the extensive loss of sarcomeres and myofibrils in the center of the cell. The loss of myofibrils, accompanied by the abnormal formation of Z-band material, often extends toward the cell periphery. The perinuclear area was completely devoid of contractile material and was filled by mitochondria of different sizes and shapes, large glycogen-containing regions, and non-specific cytoplasm (Fig. 6). The nuclei had lost their normal contour and had a tortuous appearance. The sarcoplastic reticulum was virtually absent in these severely degenerated cells and only one or two rows of regularly arranged sarcomeres remain along the cell periphery. Occurrence of cellular sequestration and cellular debris were seen in the enlarged extracellular space (Fig. 7). Other abnormalities, such as lipofuscin, fat droplets, and degenerative vacuoles were common. Myocytes of apparently normal appearance were seen in the minority.

4. Discussion

4.1. Prevalence of flow–metabolism mismatch (hibernating myocardium), normal perfused but dysfunctioning myocardium (stunned myocardium), and scar tissue

In the present study, 6.7% of the segments were assigned to scar tissue, 23.8% have shown a flow–metabolism mismatch pattern and the remaining segments were assigned to normal perfused but dysfunctioning myocard-
The small extent of scar tissue in this study population can be explained by the fact that PET viability criteria have been used in these critically ill patients for the selection process to determine whether or not the condition of an individual patient was adequate for coronary bypass surgery. Scar tissue >40% of the entire left ventricle was considered as criterion against CABG; therefore, patients with large infarcts were not included in this study [13]. However, it should be emphasized that 6.7% of dysfunctional segments, which were assigned as scar tissue may under represent the real extent of scar tissue within the left ventricle. In cases of complete occlusion of the LAD with the extent of myocardial infarction to the septal areas, infarct size would have been larger if we would not have excluded all septal areas from data analysis.

Flow–metabolism mismatch areas were observed in almost 24% of all segments. Several morphologic alterations including extensive depletion of contractile filaments accompanied by glycogen accumulation, altered mitochondrial structure, and cellular sequestration were shown by histological examination. As a consequence, the loss of myofilaments causes a reduction of the contractile capacity leading to severe preoperative wall motion abnormalities. In contrast, areas of stunned myocardium, which represented the majority of the preoperative dysfunctional myocardial segments, demonstrated a significantly higher preoperative wall motion score and less severe morphological alterations. Normal blood flow at rest to dysfunctional myocardial segments has been demonstrated by several investigators [7,9,10,14]. Myocardial stunning would explain the coexistence of normal blood flow at rest with impaired myocardial function. In patients with unstable or with exercise-induced angina, stunned myocardium has been observed [15,16]. Ambrosio et al. [16] have shown that effort angina produce prolonged reversible contractile dysfunction in the absence of perfusion abnormalities, whereas Nixon et al. [15] documented persistent regional wall motion abnormalities in patients with unstable angina, even during the pain-free period. In the present study, half of the patients had a history of stable or unstable angina pectoris, whereas the other half represented symptoms of congestive heart failure without any angina pectoris. In patients with congestive heart failure and advanced CAD, any increase in oxygen demand due to normal daily activities could lead to ischemia and to post-ischemic dysfunction. Preoperative angiographic data demonstrated elevated left ventricular enddiastolic pressures as well as elevated left ventricular volumes in all.

Fig. 4. Beginning of degeneration in stunned myocardium with slight depletion of myofilaments in the perinuclear region and occupation by glycogen, non-specific cytoplasm, and small mitochondria (original magnification × 7000).

Fig. 5. Extensive cellular degeneration in stunned myocardium. Marked loss of myofibrils, which were replaced by large areas of glycogen and non-specific cytoplasm. Small mitochondria and one giant (arrow) are present (original magnification × 7000).
but one patients (LVedVI 141.6 ± 33.1; range 86–194 ml/m² and LVesVI 100.4 ± 29.7; range 47–154 ml/m²). Increased left ventricular wall stress after ventricular dilation is a major determinant of myocardial oxygen demand and can be assumed in this specific patient population. Thus, it is conceivable that either demand- or supply-induced ischemia has led to regional myocardial dysfunction. Besides confirming previous investigations reporting the coexistence of normal blood flow at rest with impaired systolic function [6–8,17], this study also showed that the majority of the dysfunctional myocardial segments have scintigraphic pattern of apparently normal perfusion. It is conceivable that in the moderate stage of the disease in this specific patient population, myocardial dysfunction is scintigraphically characterized by little relative differences in uptake of radiolabeled flow tracers at rest and that with more persistent chronic hypoperfusion, partial exhaustion of adaptive processes may occur leading to metabolic derangements, and more severe morphological alterations. 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. Therefore, it is possible that a continuing degenerative process from stunned myocardium- to hibernating myocardium-segments exists and that a mismatch pattern represents the limits of viability.

The occurrence of even extensive cell abnormalities in segments of ‘stunned myocardium’ (Fig. 7), may serve as an indication for this assumption.

![Fig. 6. Electron microscopy of hibernating myocardium. Contractile material is absent from the cell center; sarcomeres remain only at the cell periphery (arrows). Glycogen, small mitochondria, and lipofuscin accumulate in the cytosol. Li: lipofuscin (original magnification × 6000).](image)

![Fig. 7. Occurrence of a myocyte with extensive cellular alterations and one of apparently normal appearance next to it in a biopsy of hibernating myocardium showing the existence of different degrees of myocardial injury and different states of long-term adaptation in the same area. In the enlarged extracellular space, cellular debris and cellular sequestration are seen (original magnification × 7000).](image)

![Fig. 8. Functional improvement in mean wall motion scores of ‘hibernating myocardium’, ‘stunned myocardium’ and ‘scar tissue’ are expressed as mean ± SEM. Triangles represent hibernating myocardium, circles represent stunned myocardium, squares represent ‘scar tissue’.](image)
4.2. Time-course of functional recovery and extent of improvement in flow–metabolism mismatch (MM) and normal perfused but dysfunctioning myocardium (NN)

Few clinical studies have investigated the time-course of functional recovery after coronary revascularization by serial echocardiography. While Nienaber et al. [19] have demonstrated significant improvement in regional wall thickening only 67 days after coronary angiography, Vano-verschelde et al. [20] have shown that the recovery of function is progressive over time with significant improvement in regional wall motion already after 1 week. Immediate improvement in regional wall thickening after CABG was also reported by Topol et al. [21]. Eleven days after revascularization, more than 70% of hibernating myocardium- and stunned myocardium-segments showed an improvement by at least one WM-score, confirming the early recovery of function of previous investigations [20,21]. As demonstrated in Fig. 8, both viable conditions improved in parallel; the only difference was that they were starting from different contractile levels. Different degrees of myocardial injury as shown in Figs. 3–7 are the explanation for this observation. The early improvement was also observed in the segments with preoperative severely impaired regional wall motion, suggesting that the contractile reserve of these segments was not completely absent, and that the reversal of ischemia after adequate coronary revascularization may lead to partial recovery of function. Fourteen weeks after revascularization, the majority of stunned myocardium- and hibernating myocardium-segments did not show any further improvement, indicating that either complete functional recovery has already been achieved or that a longer period may be required for complete regeneration. However, whether extensive altered myocytes have the potential of complete functional recovery after a longer period has to be questioned. In the present study, it was interesting to note that of the segments with preoperative severely impaired wall motion, only 10.3% with a mismatch pattern vs. 27.5% of stunned myocardium-segments improved by one WM-score after 1 year ($P < 0.03$). The more advanced stage of cellular alterations and the number of cells afflicted by degeneration may play a major role in the determination of the speed and the degree of functional recovery. Segments in which structural changes predominate will most likely show a delayed recovery since reparation processes or structural remodeling to regain a normal amount of contractile material requires time. The observation that only 31% of ‘stunned myocardium’ regained complete functional restoration and that in the majority of all segments hypokinesis remained, challenges the previously acknowledged definition of stunned myocardium, in which complete myocardial function is restored over time. The patient group in the present study was characterized by long-lasting advanced coronary artery disease, previous myocardial infarction, history of congestive heart failure, and very low global ejection fraction with elevated left ventricular dimensions. In patients with these preoperative characteristics, it is very unlikely that complete functional restoration will occur after revascularization since other factors such as left ventricular remodeling and persisting elevated myocardial wall stress may be responsible for the prevention of complete myocardial function. Furthermore, the existence of different degrees of myocardial injury and different states of long-term adaptation in the same patient and even in the same myocardial segment may contribute to the incomplete functional recovery despite apparently normal blood flow at rest, preoperatively. Finally, this study did not include angiographic follow-up studies; therefore, we cannot rule out the possibility that graft closure or restenosis may have contributed to the incomplete functional recovery even after 1 year of revascularization.

5. Conclusions

In patients with advanced coronary artery disease, congestive heart failure, and severe left ventricular dysfunction, preoperative scintigraphic pattern of normal perfusion associated with regional myocardial dysfunction is more pronounced than that of a flow–metabolism mismatch pattern of ‘hibernating myocardium’. Mismatch areas were associated with more severe morphological alterations, preoperative wall motion abnormalities, and incomplete postoperative recovery; whereas, in normally perfused myocardium, the recovery to normal wall motion was significantly more frequent even in segments with severely impaired myocardial function. Thus, these data suggest that a continuing degenerative process from ‘stunned myocardium’ to ‘hibernating myocardium’ exists and that ‘hibernation’ represents the limits of viability. Early surgical revascularization might be the practical consequence to prevent this progressive process finally resulting in cell death and fibrosis.

References


Appendix A. Conference discussion

Dr A. Wechsler (Philadelphia, PA, USA): It would appear that you have changed the definition of ‘stunning’. Normally you would retrospectively define stunned myocardium as myocardium that completely regained function after it was adequately perfused. Perhaps what you have called stunned is in fact hibernating and you didn’t have as much stunned myocardium as you believed.

Dr Haas: We haven’t changed the definition of stunning. We have only used the definition of stunning in the clinical point of view, that is normal blood flow at rest associated with regional myocardial dysfunction. The determination of blood flow by positron emission tomography enables us to differentiate between areas of stunned myocardium and hibernating myocardium, that is decreased or absent blood flow but maintained or increased glucose uptake. One limitation of this study is that the boundaries between stunning and hibernation are very indistinct, and that both pathophysiological processes may occur even in the same segment of analysis. However we have to deal with this problem.