Assessment of Coronary Artery Flow Velocity Pattern as a Long-Term Predictor of Left Ventricular Function and Cardiac Events after Percutaneous Coronary Intervention in Anterior Acute Myocardial Infarction

Jieli Feng, Zhaoping Li, Fuchun Zhang, Weihong Li, Xinheng Feng, Jieming Mao and Wei Gao

Abstract

Background  Coronary flow velocity (CFV) can be used to assess short-term left ventricular function recovery and the clinical prognosis of patients with acute myocardial infarction (AMI). We evaluated CFV as a predictor of long-term left ventricular function recovery and cardiac events in patients with anterior wall AMI.

Methods and Results  CFV pattern of the distal left anterior descending (LAD), wall motion score index (WMSI) and left ventricular ejection fraction (LVEF) were recorded at the points of time within 24 hours, 3 days, 6 months, and 3 years after percutaneous coronary intervention (PCI) in 50 consecutive patients with anterior wall AMI. The clinical data were collected. Patients were divided into two groups based on diastolic deceleration time (DDT) 3 days after PCI. Compared with 3 days, LVEF and WMSI in group A (DDT>600 ms, n=20) improved in 6 months and 3 years (p<0.01), but they were unchanged in group B (DDT≤600 ms, n=30). The incidence of cardiac events was higher in group B than in group A during 6 months (p<0.01). With a 3-year follow up, the incidence of chronic heart failure was higher in group B than in group A (p=0.009).

Conclusion  CFV could be used as a predictor of long-term left ventricular function recovery and cardiac events in patients with anterior wall AMI.

Key words: coronary flow velocity, acute myocardial infarction, left ventricular function, cardiac events

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Introduction

Transthoracic Doppler echocardiography (TTDE) has been used for assessment of coronary flow velocity (CFV) in the left anterior descending coronary artery (LAD) (1-3). Recent studies have demonstrated that analysis of CFV using TTDE was able to evaluate myocardial reperfusion, left ventricular function recovery and short-term complications after anterior wall acute myocardial infarction (AMI) (4, 5). Tani et al (4) recorded LAD coronary artery flow on two days after successful percutaneous coronary intervention (PCI) in 24 anterior AMI patients, and showed that patients with diastolic deceleration time (DDT) of ≤600 ms had a greater wall motion score index (WMSI) and a greater left ventricular diastolic volume at the acute phase. The left ventricular ejection fraction (LVEF) in these patients was significantly lower than in patients with DDT>600 ms at 6 months. Another study reported that numerous cardiac events were observed in inpatients with rapid diastolic deceleration of LAD flow (5). However, the relationship between LAD coronary artery velocity and long-term left ventricular systolic function recovery and cardiac events is unknown. The current study was designed to validate CFV in LAD as a predictor...
of long-term recovery of the left ventricular function and the incidence of cardiac events after PCI in patients with anterior wall AMI.

**Methods**

**Patients**

We studied 51 consecutive patients who had anterior AMI and underwent successful PCI with TIMI flow grades 2 to 3 within 12 hours after the onset of symptoms from August 2003 to December 2004 in Peking University Third Hospital. Patients who had previous myocardial infarction and acute coronary syndrome were not included in this study. All patients were first treated with PCI, and had not undergone any previous coronary heart disease treatment. The protocol was approved by the hospital's internal review board and all patients gave informed consent. The AMI diagnostic criteria were as follows: 1) typical anginal pain lasting>30 minutes, 2) ST-segment elevation>0.2mV in two or more contiguous ECG leads and 3) an increase of serum creatine phosphokinase (CK) level>3-fold of normal value. Measurement of CK and CK-MB were carried out every 6 hours through the first 24 hours after hospital admission, and the peak value was used in this study. The value of ST-segment elevation was measured manually at 60 ms after the J point using a hand-held caliper. The sum of ST-segment elevation was measured at 60 ms and the peak value was used in this study. The protocol was approved by the hospital's internal review board and all patients gave informed consent. The AMI diagnostic criteria were as follows: 1) typical anginal pain lasting>30 minutes, 2) ST-segment elevation>0.2mV in two or more contiguous ECG leads and 3) an increase of serum creatine phosphokinase (CK) level>3-fold of normal value. Measurement of CK and CK-MB were carried out every 6 hours through the first 24 hours after hospital admission, and the peak value was used in this study. The value of ST-segment elevation was measured manually at 60 ms after the J point using a hand-held caliper. The sum of ST-segment elevation was measured at 60 ms and the peak value was used in this study. The value of ST-segment elevation was measured at 60 ms after the J point using a hand-held caliper. The sum of ST-segment elevation was measured at 60 ms and the peak value was used in this study. The value of ST-segment elevation was measured at 60 ms and the peak value was used in this study.

**Coronary angiography**

PCI was performed by experienced cardiologists using the standard protocol. The success of PCI was defined as a residual stenosis of less than 30% with TIMI flow of grade 2 or 3 assessed as previously described (7). Myocardial blush grade (MBG) was assessed on the final angiogram during angioplasty and was confirmed independently and blindly on the same view of the follow-up angiogram by another experienced investigator, based on the visual assessment of contrast opacification of myocardial territory subtended by the infarct vessel as previously described (8). The criteria of MBG were as follows: 0=no myocardial blush or contrast density; 1=minimal myocardial blush or contrast density; 2=moderate myocardial blush or contrast density but less than that obtained during angiography of a contralateral or ipsilateral non-infarct-related coronary artery; and 3=normal myocardial blush or contrast density compared with that obtained during angiography of a contralateral or ipsilateral non-infarct-related coronary artery. All patients were given aspirin 300 mg and clopidogrel 300 mg before cardiac catheterization, and aspirin 100 mg/day and clopidogrel 75 mg/day during the time of follow-up.

**Echocardiography**

Serial TTDE were performed in 1 day of infarction (within 24 hours after PCI) and subsequently in 3 days by TTDE using GE vivid7 3S transducer and Sequoia C256 3.5 MHz or 6 MHz transducer. To obtain the image of the distal LAD, the transducer was placed either at the cardiac apex or at the left intercostal space above and along the interventricular groove, and focused on the proximal field. Once an optimal two-dimensional image was obtained, the transducer was rotated and tilted until one coronary segment could be visualized by color Doppler imaging (10). CFV was sampled by pulsed Doppler echocardiography. The best long-axis view in color flow imaging was obtained by optimizing the angle between the flow and Doppler beam. All studies were continuously recorded for off-line analysis. Time averaged peak systolic velocity, time averaged peak diastolic velocity, and diastolic deceleration time were calculated using the built-in system. Measurements were averaged over three cardiac cycles. Early systolic reversal flow (ESRF) was defined as a coronary flow reversal showing a peak velocity ≥10 cm/s and duration≥60 ms at early systole (11). According to DDT in 3 days, patients were divided into two groups: group A: DDT>600 ms; group B: DDT≤600 ms (12, 13).

**Clinical data collection**

Clinical data of patients including severe arrhythmia, heart function (Killip class) in the acute phase of infarction, pericardial effusion, left ventricular thrombus, re-hospitalized, and chronic heart failure (NYHA class≥2) and death during 3 years after PCI were carefully recorded in the study forms. Type and frequency of ventricular arrhythmia were monitored continuously on the first 3 days after infarction. Malignant arrhythmia (including reperfusion arrhythmia) was defined as ventricular tachycardia (a minimum of 3 consecutive beats of ventricular origin at a rate of >100 bpm), ventricular fibrillation and atrial fibrillation.
Figure 1. Examples of coronary flow velocity patterns from patients with anterior AMI. Left (group A), Coronary blood flow spectrum in 3 days after PCI in a patient without severe microvascular injury. Antegrade flow was dominant during systole. The diastolic peak velocity showed a normal deceleration. Right (group B), Coronary blood flow spectrum in 3 days after PCI in a patient with severe microvascular injury. Early systolic reversal flow was dominant, antegrade flow was decreased. The diastolic peak velocity showed rapid deceleration.

### Table 1. Baseline Clinical Characteristics of Patients

<table>
<thead>
<tr>
<th></th>
<th>Group A (n=20)</th>
<th>Group B (n=30)</th>
<th>p</th>
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</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>57±10</td>
<td>61±13</td>
<td>0.22</td>
</tr>
<tr>
<td>Male (%)</td>
<td>18 (90.0)</td>
<td>23 (76.7)</td>
<td>0.24</td>
</tr>
<tr>
<td>Risk factors (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>10 (50.0)</td>
<td>19 (63.3)</td>
<td>0.36</td>
</tr>
<tr>
<td>Diabetes mellitus</td>
<td>2 (10.0)</td>
<td>13 (43.3)</td>
<td>0.011</td>
</tr>
<tr>
<td>Hyperlipidemia</td>
<td>4 (20.0)</td>
<td>16 (53.3)</td>
<td>0.018</td>
</tr>
<tr>
<td>Smoking</td>
<td>13 (65.0)</td>
<td>18 (60.0)</td>
<td>0.48</td>
</tr>
<tr>
<td>Heart Rate (beat/min) (3 days after PCI)</td>
<td>75±10</td>
<td>78±10</td>
<td>0.29</td>
</tr>
<tr>
<td>SBP (mmHg) (3 days after PCI)</td>
<td>111±10</td>
<td>112±11</td>
<td>0.75</td>
</tr>
<tr>
<td>DBP (mmHg) (3 days after PCI)</td>
<td>64±10</td>
<td>63±9</td>
<td>0.65</td>
</tr>
<tr>
<td>ST-segment resolution ≥70% (%)</td>
<td>10 (50.0)</td>
<td>5 (16.7)</td>
<td>0.02</td>
</tr>
<tr>
<td>70−30% (%)</td>
<td>8 (40.0)</td>
<td>11 (36.7)</td>
<td>0.77</td>
</tr>
<tr>
<td>≤30% (%)</td>
<td>2 (10.0)</td>
<td>14 (46.7)</td>
<td>0.02</td>
</tr>
<tr>
<td>Time before PCI (hours)</td>
<td>8.6±5.6</td>
<td>7.4±4.9</td>
<td>0.44</td>
</tr>
<tr>
<td>Blush flow grade (%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grade ≤2</td>
<td>7 (41.2)</td>
<td>23 (79.3)</td>
<td>0.005</td>
</tr>
<tr>
<td>Grade 3</td>
<td>10 (58.8)</td>
<td>6 (20.7)</td>
<td>0.008</td>
</tr>
<tr>
<td>Peak CK-MB (U/L)</td>
<td>164±109</td>
<td>321±221</td>
<td>0.005</td>
</tr>
<tr>
<td>Echo analysis (within 24hr after PCI)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WMSI</td>
<td>1.44 ± 0.17</td>
<td>1.58 ± 0.15</td>
<td>0.019</td>
</tr>
<tr>
<td>LVEF%</td>
<td>51±5</td>
<td>47±6</td>
<td>0.11</td>
</tr>
<tr>
<td>LVEDV (mL)</td>
<td>81.1±13.5</td>
<td>93.8±23.1</td>
<td>0.08</td>
</tr>
<tr>
<td>LVESV (mL)</td>
<td>40.0±8.8</td>
<td>47.9±12.0</td>
<td>0.053</td>
</tr>
<tr>
<td>PDV (m/s)</td>
<td>0.26±0.10</td>
<td>0.44±0.18</td>
<td>0.001</td>
</tr>
<tr>
<td>PSV (m/s)</td>
<td>0.12±0.04</td>
<td>0.13±0.05</td>
<td>0.54</td>
</tr>
<tr>
<td>D duration (ms)</td>
<td>493±108</td>
<td>460±111</td>
<td>0.36</td>
</tr>
<tr>
<td>S duration (ms)</td>
<td>246±50</td>
<td>266±90</td>
<td>0.53</td>
</tr>
<tr>
<td>DDT (ms)</td>
<td>814±394</td>
<td>368±335</td>
<td>0.0004</td>
</tr>
<tr>
<td>ESRF (n)</td>
<td>2</td>
<td>14</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

PCI, percutaneous coronary intervention; SBP, systolic blood pressure; DBP, diastolic blood pressure; CK-MB, creatine phosphokinase-MB; Echo, echocardiography; WMSI, wall motion score index; LVEF, left ventricular ejection fraction; LVEDV, left ventricular end diastolic volum; LVESV, left ventricular end systolic volume; PDV, peak diastolic velocity; PSV, peak systolic velocity; DDT, diastolic deceleration time; ESRF, early systolic reversal flow.

### Statistical analysis

Results were expressed as mean ± SD. Continuous variables were compared by Student’s two-tailed t test. For comparison of variables, X² test was used. The difference of LVEF and WMSI between groups and within group A and group B at different times was calculated by two-way repeated measure ANOVA. The ability of DDT to predict occurrence of any complication was analyzed using the receiver operation characteristic curve. To evaluate the contribution of each factor to cardiac events, binary logistic regression analysis was performed. The variables included MB level, diabetes mellitus, hyperlipidemia, ST-segment resolution ≥70%, and MBG ≤ grade 2 and DDT on 3 days. p < 0.05 was considered significant. Statistical analysis was performed using prism 4.0 and SPSS 15.0.

### Results

#### Patient characteristics

The distal LAD flow was not detected in one out of 51 patients by TTDE on day 3 after PCI in our study, therefore the analysis of the results was based on the remaining 50 patients (41 men, 9 women; mean ± SD age 60±12 years); 20 patients were included in group A (DDT>600 ms) (Fig. 1), and 30 patients were included in group B (DDT ≤ 600 ms). In group A, only one patient was given dopamine, 95% (19/20) patients were given beta blocker, and all patients were given nitroglycerin, angiotensin II-converting enzyme inhibitor, clopidogrel, aspirin and statin in 3 days after successful PCI. In group B, one patient was given sodium nitroprusside, 3 patients were given dopamine, 6 patients were given diuretic, 96.7% (29/30) patients were given angiotensin II-converting enzyme inhibitor, 93.3% (28/30) patients were given beta blocker, and all patients were given nitroglycerin, clopidogrel, aspirin and statin in 3 days after successful PCI. Treatment was not significantly different between 2 groups.

The clinical characteristics of the patients were summarized in Table 1. In group B 40% (12/30) patients had mul-
Figure 2. There was no statistical deference in LVEF between the two groups in 1 day after PCI (p=0.11). In 3 days, LVEF was significantly lower in group B than that in group A (p<0.001). LVEF significantly improved in group A in 3 days compared with that within 24 hours after PCI (p=0.004), but no significant changes of LVEF were observed in group B (p=0.32). In 6 months and 3 years follow-up, LVEF were significantly higher in 6 months and 3 years after PCI compared with that in 3 days in group A (p=0.014, and p=0.011). WMSI were significantly lower in 6 months and 3 years after PCI compared with that in 3 days in group A (p=0.008, and p=0.014). LVEF and WMSI remained unchanged in 6 months and 3 years after PCI compared with that in 3 days in group B. PSV, D duration, S duration were no significant differences between 2 groups in 3 days. PDV, PSV, D duration, S duration DDT were all no significant differences between 2 groups at 6 months.

Figure 3. Correlation between deceleration time of diastolic flow velocity (DDT) in 3 days and left ventricular ejection fraction (LVEF) in 6 months after PCI. Results showed significant correlation between DDT and LVEF (r=0.60, p<0.001).

Table 2. Echocardiography and Coronary Flow Velocity Analysis of Patients

<table>
<thead>
<tr>
<th></th>
<th>3 days after PCI</th>
<th>6 months after PCI</th>
<th>3 years after PCI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GroupA (n=20)</td>
<td>GroupB (n=30)</td>
<td>p</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LVEF(%)</td>
<td>56±5</td>
<td>49±6</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>WMSI</td>
<td>1.32±0.14</td>
<td>1.57±0.18</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>LVEDV(mL)</td>
<td>84±24.6</td>
<td>97.5±25.4</td>
<td>0.08</td>
</tr>
<tr>
<td>LVESV(mL)</td>
<td>38±12</td>
<td>49±13</td>
<td>0.003</td>
</tr>
<tr>
<td>PDV(m/s)</td>
<td>0.29±0.14</td>
<td>0.44±0.17</td>
<td>0.002</td>
</tr>
<tr>
<td>PSV(m/s)</td>
<td>0.15±0.06</td>
<td>0.15±0.05</td>
<td>0.89</td>
</tr>
<tr>
<td>D duration(ms)</td>
<td>477±88</td>
<td>425±105</td>
<td>0.07</td>
</tr>
<tr>
<td>S duration (ms)</td>
<td>233±58</td>
<td>239±63</td>
<td>0.71</td>
</tr>
<tr>
<td>DDT(ms)</td>
<td>999±314</td>
<td>252±104</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>ESRF(n)</td>
<td>0</td>
<td>15</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

LVEF, left ventricular ejection fraction; WMSI, wall motion score index; LVEDV, left ventricular end diastolic volum; LVESV, left ventricular end systolic volume; PDV, peak diastolic velocity; PSV, peak systolic velocity; DDT, diastolic deceleration time; ESRF, early systolic reversal flow. LVEF were significantly improved in 6 months and 3 years after PCI compared with that in 3 days in group A (p=0.014, and p=0.011). WMSI were significantly lower in 6 months and 3 years after PCI compared with that in 3 days in group A (p=0.008, and p=0.014). LVEF and WMSI remained unchanged in 6 months and 3 years after PCI compared with that in 3 days in group B. PSV, D duration, S duration were no significant differences between 2 groups in 3 days. PDV, PSV, D duration, S duration DDT were all no significant differences between 2 groups at 6 months.
Figure 4. Correlation between deceleration time of diastolic flow velocity (DDT) in 3 days and left ventricular ejection fraction (LVEF) in 3 years after PCI. Results showed significant correlation between DDT and LVEF ($r=0.46$, $p=0.006$).

Left ventricular systolic function and left ventricular remodeling

Both LVEF and WMSI were significantly improved in group A on day 3 compared with that within 24 hours after PCI ($p<0.01$), but no significant changes of LVEF and WMSI were observed in group B. In particular, LVEF and WMSI remained unchanged in 6 months and 3 years after PCI compared with that on day 3 in group B, while both LVEF and WMSI were significantly improved in group A with that on day 3 in group B, while both LVEF and WMSI were significantly improved in group A on day 3 compared with that within 24 hours after PCI ($p<0.01$), but no significant changes of LVEF and WMSI were observed in group B. In particular, LVEF and WMSI remained unchanged in 6 months and 3 years after PCI compared with that on day 3 in group B, while both LVEF and WMSI were significantly improved in group A (Table 2, Fig. 2). DDT in 3 days had a positive correlation with LVEF at 6 months and 3 years, $r=0.60$ ($p<0.001$) and $r=0.46$ ($p=0.006$) (Fig. 3, 4).

Left ventricular remodeling was assessed by 20% increase of LVEDVI as previously described (14). The result showed that the remodeling occurred in 4 patients (25%) in group A and in 7 patients (23.3%) in group B at 6 months follow-up (Table 3).

Coronary flow velocity analysis

Coronary flow could not be observed in 3 patients in group B and in 5 patients in group A within 24 hours after PCI because patients could not change posture after femoral artery puncture operation, and an optimal interventricular groove two-dimensional image and coronary flow color image could not be obtained. However, coronary flow could be observed in all patients in 3 days. DDT of group A was significantly longer than that of group B at 24 hours after PCI and in 3 days ($814\pm394$ ms vs. $368\pm335$ ms, $p<0.001$ and $999\pm314$ ms vs. $252\pm104$ ms, $p<0.001$). ESRF was observed in 14 patients within 24 hours after PCI and in 15 patients in 3 days in group B, while it was only seen in 2 patients within 24 hours and none on day 3 in group A. The details of CFV parameters are shown in Table 2 and Table 1. All of the above parameters were measured in 3 cycles by one observer, and averages were obtained. Intra-observer variability of the measurements was 1.6%.

Complications

In the 3-year follow-up, we observed more cardiac complications in group B than in group A (Table 3): 2 patients died from heart failure, 1 patient died from sudden death as well as 1 patient died from unrelated death (suicide). There were no significant differences in the incidence of arrhythmia, heart failure, death, reinfarction, and thrombus between patients with MBG $\leq 2$ and patients with MBG 3. There was a significant difference only in the incidence of cardiac effusion between patients with MBG $\leq 2$ and patients with MBG 3. There was a significant correlation between Killip grades and DDT ($r=-0.4$, $p=0.003$), but not MBG. There was a significant difference only in the incidence of arrhythmia between patients with ECG ST complete resolution and patients with ECG ST no complete resolution. Binary logistic regression analysis showed that, compared with MB level, diabetes mellitus, hyperlipidemia, ST-segment resolution $\geq 70$%, and MBG $\leq$ grade 2, DDT $\leq 600$ ms and MBG $\leq$ grade 2 were significant predictors of NYHA $\geq$ 2 class (OR=0.992, CI=0.984-1.0, $p=0.032$, and OR=124.8, CI=120.0-129.6, $p=0.019$). By the ROC curve method, the threshold value of DDT was 338 ms to predict cardiac failure and arrhythmia; the sensitivity was 75.0%, specificity was 73.1%. The area under the curve (AUC) was 0.77.

Discussions

We recorded coronary blood flow of LAD in 97% patients (50/51 patients), and validated TTDE to be a useful non-invasive method to investigate coronary flow of LAD and to predict long-term recovery of the left ventricular function and the incidence of cardiac events after PCI in anterior AMI patients.

Relationship between CFV and no-reflow phenomenon

Previous studies showed that up to 30% of patients undergoing primary angioplasty lacked myocardial reperfusion despite recanalization of the infarct-related artery, and microvascular embolization of plaque material and thrombus content can occur spontaneously or iatrogenically during the PCI procedure (15, 16). In patients with no-reflow, the coronary microvasculature was profoundly damaged, leading to an increased microvascular impedance and decreased intramyocardial blood pool (17). The no-reflow phenomenon in ACS may be caused not only by distal embolization of thrombi, but also by mechanical disruption of culprit plaque consisting of large amounts of the necrotic core component, which has been shown to be the most thrombogenic of the components of human atherosclerotic plaques, with secondary accumulation of platelets and fibrin and plugging of the coronary microvasculature with plaque components (18). A previous study reported (3) that the severity of microvas-
Circulatory dysfunction varied with time after coronary reperfusion. As a result of reperfusion injury, the no-reflow phenomenon might progress within the first 48 hours after coronary reperfusion, and coronary flow would change. In the present study, we did serial measurement, and found ESRF was observed in 14 patients within 24 hours after PCI and in 15 patients in 3 days in group B, while it was only seen in 2 patients within 24 hours and none on day 3 in group A. Thus, recording the coronary flow pattern after 48 hours after PCI was a good time point to assess myocardial tissue perfusion.

A few methods have been previously used to assess no-reflow phenomenon, for example, myocardial contrast echocardiography (MCE), coronary angiography TIMI grade, MBG and cardiac magnetic resonance imaging (CMRI). Iwakura et al (19) reported that in patients with a no-reflow phenomenon defined by MCE, the CFV pattern, assessed using a Doppler guidewire, was characterized by the appearance of ESRF, diminished systolic antegrade flow and rapid deceleration of diastolic flow. ESRF and shorter DDT had been observed frequently with no-reflow cases of AMI after successful recanalization and were explained by perivascular edema, capillary leukocyte plugging and an increase in coronary vascular resistance caused by such ischemic microvascular damage (19). Recently, TTDE has been used to investigate coronary flow of LAD with high success rate. In the present study, we successfully recorded 50 out of 51 patients (97%) at day 3 after PCI; 30% of patients had ESRF and 60% of patients had shorter DDT. Recently, CMRI is also used in the assessment of myocardial perfusion after PCI in patients with AMI (20, 21), but this technology is expensive. Compared with MCE and CMRI, TTDE is more cost-effective, therefore measuring CFV by TTDE more feasible to use in the clinic.

TIMI grade was a common method used to assess myocardial tissue. But studies by MCE had revealed that no-reflow occurred in about 30% of the patients having TIMI-3 flow after PCI, suggesting low sensitivity of TIMI grading, although a high specificity for assessing the no-reflow phenomenon (15). MBG was a better method to assess the level of myocardial perfusion. CFV pattern and MBG reflect different aspects of impaired microvascular function after acute myocardial infarction. MBG gave direct evidence of microvascular perfusion at the myocardial tissue level. In contrast, the CFV pattern was an index that only indirectly reflects the status of the microcirculation (22). The study of Hoffmann et al (22) showed that blush grade was the only variable that was correlated with the diastolic deceleration rate as an important index of the coronary flow velocity pattern, while age, sex, infarct location, time to revascularization, reference vessel diameter, and peak serum creatine kinase had no significant impact on the diastolic deceleration rate. Our result showed that in patients with shorter DDT patients, 60% had MBG≤2. The two parameters were also consistent in the evaluation of reperfusion in AMI. Because coronary angiography was an invasive method, CFV was a better method to serially evaluate myocardial reperfusion.

Persistent ST-elevation after PCI in AMI patients is associated with impaired microvascular reperfusion (23). This was usually happened in patients with a large infarct size (24) and a poor clinical outcome (21). Santoro et al (25) reported that ST resolution, recorded 30 minutes after successful coronary intervention, predicted no-reflow on the contrast echocardiogram with 77% sensitivity and 91% specificity. In the present study, patients with persistent ST-elevation had shorter DDT, indicating coordinate change of these two parameters. A linear relationship between the level of CK and size of myocardial infarction, and the level of CK was a good marker to assess the size of myocardial infarction (26). Gibson et al (27) reported that creatinine kinase-MB elevation after PCI was associated with TIMI perfusion grade but not with TIMI flow grade or TIMI frame count, indicating that creatinine kinase-MB elevation could instead be related more with tissue reperfusion than with epicardial coronary flow. In the present study, patients with shorter DDT had a higher creatinine kinase-MB level, and DDT had a positive relationship with the level of CK-MB. A previous study (28) showed that no-reflow detected by diastolic deceleration time<185 ms had a far higher sensitivity and specificity than TIMI frame count, ST resolution and creatinine kinase-MB. Therefore, coronary flow pattern provided a good method to assess myocardial reperfusion.

**Coronary flow velocity and complications**

It is important to predict complications of AMI. Yamamura et al (11) measured CFV using Doppler guidewire in the early stage of AMI in 169 patients with anterior wall infarction who had been successfully treated with PCI. They found that patients with DDT≤600 ms and ESRF had higher incidence of severe arrhythmia, heart failure, heart rupture, sudden death, reinfarction, thrombus and pericardial effusion. In another study by the same group (5), they also found that patients with shorter DDT measured with TTDE had more complications until hospital discharge, and DDT≤600 ms and TIMI 2 flow after PCI were independent predictors of CHF. However, only DDT≤600 ms contributed significantly to the occurrence of left ventricular thrombus and cardiac tamponade. Similarly, DDT≤600 ms and late reperfusion were independent predictors of precordial effusion. From our study, the incidences of arrhythmia and Killip≥2 class in group B were also higher than those in group A at an early stage of AMI. But there was no significant difference in the incidence of arrhythmia, heart failure death, reinfarction, and thrombus between patients with MBG≤2 and patients with MBG 3. Only 4 patients in group B died. There was a significant correlation between killip grades and DDT (r=-0.4, p=0.003), but not the blush grade.

The long-term prognosis in patients with AMI has attracted more concern by clinicians. In the first 6 months, we found a significantly higher incidence of ventricular thrombus, cardiac effusion, cardiac aneurysm and ventricular re-
Table 3. Clinical Complications of Patients

<table>
<thead>
<tr>
<th></th>
<th>time point</th>
<th>Group A (n=20)</th>
<th>Group B (n=30)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arrhythmia (%)</td>
<td>in hospital</td>
<td>5 (25)</td>
<td>21 (70)</td>
<td>0.001</td>
</tr>
<tr>
<td>Killip≥2 class (%)</td>
<td>in hospital</td>
<td>1 (5)</td>
<td>13 (43.3)</td>
<td>0.005</td>
</tr>
<tr>
<td>Cardiac tamponade (%)</td>
<td>In hospital</td>
<td>0</td>
<td>1 (3.3)</td>
<td>0.25</td>
</tr>
<tr>
<td>Cardiac thrombus (%)</td>
<td>6 moths</td>
<td>0</td>
<td>7 (23.3)</td>
<td>0.019</td>
</tr>
<tr>
<td>Pericardial effusion (%)</td>
<td>6 moths</td>
<td>4 (20)</td>
<td>15 (50)</td>
<td>0.032</td>
</tr>
<tr>
<td>Cardiac aneurysm (%)</td>
<td>6 moths</td>
<td>0</td>
<td>2 (6.6)</td>
<td>0.25</td>
</tr>
<tr>
<td>Reinfarction (%)</td>
<td>6 moths</td>
<td>0</td>
<td>2 (6.6)</td>
<td>0.25</td>
</tr>
<tr>
<td>Ventricular remodeling (%)</td>
<td>6 moths</td>
<td>4 (25)</td>
<td>7 (23.3)</td>
<td>0.1</td>
</tr>
<tr>
<td>NYHA≥2 class (%)</td>
<td>3 years</td>
<td>0</td>
<td>8 (26.7)</td>
<td>0.007</td>
</tr>
<tr>
<td>Cardiac death (%)</td>
<td>3 years</td>
<td>0</td>
<td>3 (10)</td>
<td>0.09</td>
</tr>
<tr>
<td>Re-hospitalization (%)</td>
<td>3 years</td>
<td>0</td>
<td>4 (23.3)</td>
<td>0.09</td>
</tr>
</tbody>
</table>

molding in patients with DDT≤600 ms. For the 4 dead patients and one patient who had cardiac tamponade, their DDT were all≤600 ms. The incidence of pericardial effusion and left ventricular thrombus both seem quite high in group B. Sugiura reported that incidence of pericardial effusion in the acute phase persisted to 1 month after the onset of AMI after successful primary PTCA reached 38%, which alonged with Killip class>1 and the absence of collaterals (29). All patients had anterior wall AMI in our study. The incidence of pericardial effusion reached 50% in group B, who along with poor myocardial reperfusion. In the study of Van Dantzig et al (30), the incidence of the detection of left ventricular thrombus by TTDE in subjects with anterior AMI was 20% to 40%, whereas in cases of AMI in an inferior location it is only 1% to 5%. The intracavitary thrombosis was obviously associated with structural and functional damage to the myocardium. In the present study, a 23% incidence of left ventricular thrombus was found in group B. After 3 years of follow up, 8 patients had chronic heart failure in group B, 4 of them were re-admitted to hospital and one died from heart failure, but no patients had chronic heart failure in group A. Binary logistic regression analysis showed that, compared with MB level, diabetes mellitus, hyperlipidemia, ST-segment resolution≥70%, and MBG≤grade 2, DDT and MBG≤grade 2 were significant predictors of NYHA≥2 class. Therefore, these results suggest that microvascular injury after reperfusion is an important contributor to long-term adverse cardiac events. DDT of coronary flow was also an important and feasible mark to predict cardiac events of patients with anterior AMI.

In present study, there were more patients with diabetes in group B than in group A, indicating that diabetic subjects had poor microvascular perfusion. One explanation is that postprandial hyperglycemia might cause endothelial dysfunction, and endothelial dysfunction results in an imbalance between relaxing and contracting factors, prothrombotic state, inflammatory response, vasoconstrictive substance release, and subsequent plaque instability in the coronary arteries (31).

Coronary flow velocity and LV systolic function

A previous study (4) had determined LV systolic function in 24 patients during 6 months after anterior AMI. In the acute phase, LV systolic function of patients with DDT≤600 ms showed no significant differences compared with that of patients with DDT>600 ms. However, the LVEF of patients with DDT≤600 ms were significantly lower than that of patients with DDT>600 ms, and WMSI of patients with DDT≤600 ms was significantly greater than that of patients with DDT>600 ms at 6 months after PCI. This suggested that CFV of the LAD could predict wall-motion in an early stage of AMI. Our study had followed the LV systolic function for 3 years in patients who had PCI after AMI. The result showed that DDT on day 3 after PCI had a positive correlation with both LVEF in 6 months and 3 years. Patients with DDT≤600 ms had a poor left ventricular function at acute phase, which did not improve in 6 months and 3 years. However, patients with DDT>600 ms had only a mild left ventricular injury at acute phase, and LV systolic function was improved in 6 months and 3 years. Patients with DDT≤600 ms had severe microvascular injury and poor recovery of left ventricular function, indicating that CFV in 3 days after PCI was a good predictor of the long-term left ventricular function.

Limitations of the study

As only LAD flow had a high detection rate by TTED, only patients with anterior wall infarction were included in the study. In our previous report, only 70% of right coronary flow could be detected by TTDE (32). It would be worthwhile to study the right coronary flow pattern in patients with acute inferior wall infarction in the future.

Conclusions

In patients with anterior wall infarction, shorter DDT in LAD on day 3 after PCI correlates with poor left ventricular systolic function and its recovery as well as high incidence of long-term cardiac events. Our results suggest that CFV can be used as a predictor of long-term recovery of the left
ventricular function and the incidence of cardiac events after PCI in patients with anterior AMI.

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