Assessing myocardial perfusion with the transthoracic Doppler technique in patients with reperfused anterior myocardial infarction: comparison with angiographic, enzymatic and electrocardiographic indices

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Received 6 December 2003; revised 5 June 2004; accepted 10 June 2004
Available online 14 August 2004
See page 1480 for the editorial comment on this article (doi:10.1016/j.ehj.2004.06.029)

Aims Doppler guidewire studies demonstrated that the no-reflow phenomenon in acute myocardial infarction is associated with characteristic coronary blood flow pattern. We investigated the potential of coronary flow measurement with transthoracic Doppler technique to detect the no-flow in the patients with reperfused infarction, and compared it to that of other modalities.

Methods and results We performed intracoronary myocardial contrast echocardiography after successful primary coronary intervention in the 94 patients with first, anterior wall infarction. Coronary blood flow in the left anterior descending artery was detected with transthoracic Doppler echocardiography within 24 h after reperfusion in 83 patients (88.3%). Twenty-two patients with the no-reflow had significantly lower systolic peak velocity (5.1 ±4.2 vs. 8.1 ±6.2 cm/s, \( p = 0.04 \)), higher diastolic peak velocity (38.2 ±10.3 vs. 30.8 ±15.7 cm/s; \( p = 0.04 \)), and shorter diastolic deceleration time (134 ±41 vs. 424 ±202 ms; \( p < 0.0001 \)) than those with good-reflow. Systolic flow reversal was more frequently observed in those with no-reflow (18.2% vs. 3.3%, \( p = 0.02 \)). Diastolic deceleration time <185 ms detected the no-reflow with far higher sensitivity/specificity (95.5%/95.1%) than TIMI frame count (45.5%/91.8%), ST resolution (54.5%/73.8%) and creatinine kinase-MB (54.5%/88.5%).

Conclusion Analysing coronary blood flow pattern can detect the no-reflow after anterior infarction better than other angiographic, electrocardiographic and enzymatic modalities.

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Introduction

The no-reflow phenomenon is observed in about 30% of the patients with acute myocardial infarction even after...
successful primary percutaneous coronary intervention,\textsuperscript{1,2} and it is associated with greater infarct size, poorer functional recovery and higher incidence of complications.\textsuperscript{3,4} Achieving tissue-level perfusion is a goal of reperfusion therapy, and myocardial contrast echocardiography\textsuperscript{1–3} and magnetic resonance imaging\textsuperscript{4} are quite useful to assess it. However, they are hardly applied to all patients in the acute stage of infarction.

The Doppler guidewire study demonstrated that the no-reflow is associated with characteristic coronary blood flow velocity pattern;\textsuperscript{5} systolic flow reversal, reduced systolic antegrade flow and rapid deceleration of diastolic flow velocity. Recent technological advancement has made it possible to measure coronary flow velocity in the left anterior descending artery non-invasively with the transthoracic Doppler technique.\textsuperscript{6–9} In the present study, we investigate the ability of measuring coronary blood flow with transthoracic Doppler technique to assess the no-reflow after anterior wall infarction, and compared it to those of other angiographic, electrocardiographic and enzymatic indices.

**Methods**

**Study population**

We studied 101 patients with first, anterior wall myocardial infarction consecutively referred to our hospital within 24 h after the onset of symptoms between October 1999 and September 2001. Diagnosis of acute myocardial infarction was made if the patient showed the following: prolonged chest pain (>30 min), ST-segment elevation ≥2 mm in at least two pre-cordial electrocardiographic leads and ≥3-fold increase in serum creatinine kinase level. Six patients were excluded due to incomplete data collection and one due to suboptimal result of coronary intervention. Therefore, the final study population consisted of 94 patients. The study protocol was approved by the Hospital Ethics Committee.

**Protocol**

Just after the admission, we recorded a 12-lead electrocardiogram and two-dimensional echocardiogram using a commercially available echocardiography SONOS 5500 with 53 transducer (image frequency 2–4 MHz) on harmonic fusion mode (Philips Medical Systems, Andover, MA, USA). Each patient received aspirin (243 mg) at least 30 min before coronary intervention. After the intravenous heparin injection (100 U/kg), we performed left and right coronary angiography and left ventriculography using the femoral approach with Judkins’ technique. We performed primary coronary intervention to achieve residual diameter stenosis of ≤25%. Then we performed myocardial contrast echocardiography with intracoronary injection of 2 mL of sonicated loxaglate (Hexabrix-320, Tanabe, Tokyo, Japan) using SONOS 100CS (Philips Medical Systems: image frequency 2.5 MHz, frame rate 21 Hz) as previously reported.\textsuperscript{1,3,10}

We recorded coronary flow velocity spectrum in the coronary care unit within 24 h (mean time 18.0±4.9 h) after reperfusion with an ultra-wide band frequency transducer (7–12 MHz) installed on the SONOS 5500.\textsuperscript{11} We placed the transducer approximately along the midclavicular line in the fourth to fifth intercostal spaces. At first, we obtained a short axis of the left ventricular apex and of the anterior groove. Then, we searched coronary flow signals in the left anterior descending artery under the guidance of colour Doppler flow mapping (Fig. 1). The transducer was rotated counterclockwise to obtain the best long-axis colour view. When a diastolic flow was recognised in the anterior groove area, it was brought into the centre of the ultrasound field by angling laterally and slightly above the central ray of the scan plane. We placed a sample volume (5×2.5 mm) on the colour signal in the distal portion of coronary artery to record coronary flow velocity using the pulsed Doppler. Only when the Doppler incident angle was greater than 30°, we made an angle correction. We repeated the two-dimensional echocardiographic examination 4 weeks later.

**Analysis of coronary flow velocity pattern**

Two independent cardiologists, blinded to patients’ data, evaluated coronary flow velocity spectrum of each examination. We measured antegrade systolic peak velocity (cm/s), peak diastolic velocity (cm/s) and diastolic deceleration time (ms) (Fig. 1). We gave 0 cm/s to systolic peak velocity when systolic antegrade flow was not observed. These parameters were calculated as the mean of at least two cardiac cycles. The prevalence of systolic flow reversal was also compared between the patients with and without no-reflow. We have reported the reproducibility of measuring the coronary flow velocity parameters previously.\textsuperscript{11}

**Analysis of echocardiographic data**

An independent observer, blinded to patients’ data, evaluated the wall motion of 16 myocardial segments\textsuperscript{12} in echocardiograms on admission and at the follow-up study. The wall thickening of each myocardial segment was scored as follows: 4=dyskinesia, 3=akinesia, 2=severe hypokinesia, 1=hypokinesia and 0=normokinesia or hyperkinesia. We defined the risk area as myocardial segments showing dyskinesia, akinesia or severe hypokinesia on admission. Wall motion score was calculated as the sum of the scores within the risk area. We calculated left ventricular ejection fraction using the Teicholz method.

Two experienced echocardiographers analysed myocardial contrast echocardiograms to determine the presence of the no-reflow phenomenon. We defined the no-reflow zone as a contrast perfusion defect within the risk area in apical 2- and/or 4-chamber images at end-diastole. We quantified the area of no-reflow as a ratio to the risk area by measuring corresponding endocardial length.\textsuperscript{1,3} Myocardial reperfusion was considered the no-reflow phenomenon when the ratio exceeded 25%, which is a good cut-off point to assess the patients with poor clinical and functional prognosis\textsuperscript{1,3,10} although it may be somewhat arbitrary. We have reported the reproducibility of measuring the size of contrast defect previously.\textsuperscript{1}

**Analysis of coronary angiography**

Two experienced interventional cardiologists, blinded to patients’ data, analysed the coronary angiograms to determine the Thrombolysis in Myocardial Infarction (TIMI) flow grade and TIMI flow count, the frame count required for dye to first opacify a standard distal landmark,\textsuperscript{13} in the culprit artery after coronary intervention. Collateral channels were graded according to the report by Rentrop,\textsuperscript{14} and good collateral was defined as grade 2 or 3.
Analysis of electrocardiography

An experienced cardiologist, blinded to patients’ data, analysed electrocardiograms recorded upon hospital admission and 60 min after coronary intervention procedure. The sum of ST-segment elevation 20 ms after the J point was calculated and compared with that on admission. Resolution of more than 70% of ST-elevation was considered as the electrographic sign of successful myocardial perfusion.

Statistics

All data are expressed as mean±SD. We made multiple comparisons by one-way ANOVA and significance of difference was calculated with Scheffe’s F post hoc test. We compared categorical variables by using the χ² test. We analysed the relations between numerical variables with linear regression analysis with Pearson’s correlation co-efficient. To analyse the predictive value of variables, we constructed receiver operating characteristic curves with MedCalc 7.2 (MedCalc Software) and determined the suitable cut-off point where sensitivity is nearly equal to specificity as possible. Area under the curve±standard error in the receiver operating characteristic curve was also determined as a scalar measure of performance independent of the decision criterion. Differences were considered significant at p<0.05 (two-sided). We performed multiple imputation of missing data with NORM version 2 (Schafer, JL, 1999, Department of Statistics, Pennsylvania State University) with the assumption that the missing values were “missing at random” in the sense defined by the statistics. NORM uses the multivariate normal distribution model as a probability model on the complete data. Other statistical analyses were performed with StatView 5.0 (SAS Institute, Heidelberg, Germany).

Results

Patients’ characteristics

Among the 94 study patients (mean age 60±12 years; range 25–91 years), 77 were male. The culprit lesion was at the proximal portion of the left anterior descending artery in 57 patients (60.6%) and at the middle portion in 37 patients. The mean time from the symptom onset to reperfusion was 7.9±7.1 h, and peak creatinine kinase and creatinine kinase-MB levels were 2444±1689 and 178±125 IU/L, respectively.
Twenty five patients (26.6%) showed the no-reflow phenomenon on myocardial contrast echocardiogram, and the remaining 69 patients were classified as good-reflow. The patient with no-reflow had higher peak creatinine kinase-MB (258 ±139 vs. 149 ±106, p =0.003), and higher wall motion score on admission (15 ±6 vs. 11 ±6, p =0.008) and on follow-up echocardiography (19 ±5 vs. 15 ±5, p =0.008) than those with good-reflow. Recovery ≥ one score in wall motion score was observed in 58 patients (84%) in those with good-reflow, but only in 15 patients (60%) with no-reflow (p =0.03). The patients with good-reflow also showed better ejection fraction on admission and at the follow-up study than those with no-reflow (Table 1). At the follow-up study, ejection fraction less than 40% was observed in eight (32%) in the no-reflow arm, but only in three (4%) in the good-reflow arm (p =0.0009).

Proximal culprit lesion was more frequently observed in the no-reflow arm than the good-reflow arm. After intervention, TIMI grade 2 flow was observed in culprit artery in 14 (56%) patients with no-reflow, and the remaining 11 patients showed TIMI 3 flow, while 63 (91.3%) patients with good-reflow showed TIMI 3 flow (p =0.0002). ST resolution was observed on electrocardiogram recorded 60 min after reperfusion in 52 (75.4%) patients with good-reflow but only in 10 (40.0%, p =0.001) with no-reflow. Those with good-reflow also showed fewer TIMI frame count than those with no-reflow (37 ±22 vs. 57 ±39, respectively; p =0.003). There were no significant differences in age, gender, elapsed time from onset to reperfusion, coronary risk factors, stent usage and collateral grade between the two subgroups (Table 1).

### Table 1 Clinical characteristics of the study patients

<table>
<thead>
<tr>
<th></th>
<th>Reflow</th>
<th>No-reflow</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of patients</td>
<td>69</td>
<td>25</td>
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<tr>
<td>Age (year)</td>
<td>60±11</td>
<td>59±14</td>
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<tr>
<td>Male gender (%)</td>
<td>82.6</td>
<td>80.0</td>
<td>0.77</td>
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<tr>
<td>Risk factors</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Diabetes Mellitus (%)</td>
<td>34.7</td>
<td>16.0</td>
<td>0.07</td>
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<tr>
<td>Hypertension (%)</td>
<td>46.4</td>
<td>36.0</td>
<td>0.37</td>
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<td>Hyperlipidaemia (%)</td>
<td>34.7</td>
<td>44.0</td>
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<td>Smoking (%)</td>
<td>63.8</td>
<td>64.0</td>
<td>0.98</td>
</tr>
<tr>
<td>Symptom onset to reflow time (h)</td>
<td>7.8±7.3</td>
<td>8.3±6.5</td>
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</tr>
<tr>
<td>Peak creatinine kinase (IU/L)</td>
<td>2059±1486</td>
<td>3520±1783</td>
<td>0.0002</td>
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<tr>
<td>Peak creatinine kinase-MB (IU/L)</td>
<td>149±106</td>
<td>258±139</td>
<td>0.0003</td>
</tr>
<tr>
<td>Wall motion score on admission</td>
<td>15±5</td>
<td>19±4</td>
<td>0.0008</td>
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<tr>
<td>Wall motion score at follow up study</td>
<td>11±6</td>
<td>15±6</td>
<td>0.008</td>
</tr>
<tr>
<td>Ejection fraction on admission (%)</td>
<td>49±11</td>
<td>43±8</td>
<td>0.0003</td>
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<tr>
<td>Ejection fraction at follow up study (%)</td>
<td>54±10</td>
<td>45±8</td>
<td>0.0001</td>
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<tr>
<td>Stent implantation (%)</td>
<td>49.3</td>
<td>64.0</td>
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<td>Proximal culprit lesion (%)</td>
<td>53.6</td>
<td>80.0</td>
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<td>Good collateral channels (%)</td>
<td>30.4</td>
<td>16.0</td>
<td>0.16</td>
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<tr>
<td>TIMI flow grade 3 after intervention (%)</td>
<td>91.3</td>
<td>44.0</td>
<td>0.0002</td>
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<td>TIMI frame count, frame</td>
<td>37±22</td>
<td>57±39</td>
<td>0.003</td>
</tr>
<tr>
<td>ST resolution at 60 min (%)</td>
<td>75.4</td>
<td>40.0</td>
<td>0.001</td>
</tr>
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</table>

Proximal culprit lesion = Culprit lesion proximal to the first septal branch. Good collateral channels = collaterals graded as 2 or 3. Data are presented as the mean value ± SD or percent of patients.

**Coronary flow velocity pattern and the no-reflow phenomenon**

We obtained reliable coronary flow velocity spectrums in 83 out of 94 study patients (88.3%) (Fig. 1). Systolic antegrade flow was observed in 15 patients with no-reflow (68.2%) and 46 patients with good-reflow (75.4%, p =0.51). The no-reflow arm showed significantly lower systolic peak velocity (5.1 ±4.2 vs. 8.1±6.2 cm/s, respectively; p =0.04), higher diastolic peak velocity (38.2±10.3 vs. 30.8±15.7 cm/s; p =0.04) and shorter diastolic deceleration time (133±41 vs. 423±203 ms; p =0.0001) than the good-reflow arm (Table 2). Systolic flow reversal was observed in four patients with no-reflow (18.2%) and two with good-reflow (3.3%; p =0.02).

Diastolic deceleration time was also weakly but significantly correlated to wall motion score at the follow-up study (r =0.48, p <0.0001) (Fig. 3), whereas systolic or diastolic peak velocity showed no significant correlation to wall motion score.
(38.0 ± 9.7 vs. 31.5 ± 15.7 cm/s) did not reach statistical significance (p = 0.06).

Assessment of the no-reflow phenomenon

The ability of coronary flow velocity parameters to predict the no-reflow phenomenon was assessed with the receiver operating characteristic curve analysis (Table 3). The area under the curve of deceleration time was 0.96 ± 0.02 (Fig. 2). Using 185 ms as the suitable cut-off point determined with the receiver operating characteristic curve analysis, deceleration time could detect the no-reflow phenomenon with 95.5% sensitivity and 95.1% specificity. The areas under the curve of systolic and diastolic peak velocity were only 0.63 ± 0.07 and 0.70 ± 0.07, respectively, and they were smaller than that of deceleration time (p < 0.0001). Using 6.7 cm/s as the cut-off point, systolic peak velocity detected the no-reflow with only 72.7% sensitivity and 57.4% specificity. The appearance of systolic flow reversal detected it only with 18.2% sensitivity but 96.7% specificity.

TIMI-2 flow in the culprit artery after coronary intervention detected the no-reflow with 54.5% sensitivity and 93.4% specificity. The area under the curve of frame count was 0.64 ± 0.07, which was smaller than that with deceleration time (p = 0.0001). Using 52 frames as the cut-off point, frame count detected the no-reflow with 45.5% sensitivity and 91.8% specificity (Table 3).

| Table 2 | Coronary flow velocity parameters in the patients with anterior wall acute myocardial infarction |
|------------------------|------------------------|------------------------|
| Reflow (n = 61)         | No-reflow (n = 22)     | p-value                |
| Systolic peak velocity (cm/s) | 8.1 ± 6.2            | 5.1 ± 4.2              | 0.04                   |
| Diastolic peak velocity (cm/s) | 30.8 ± 15.7          | 38.2 ± 10.3            | 0.04                   |
| Diastolic deceleration time (ms) | 423 ± 203           | 133 ± 41               | <0.0001                |
| Systolic flow reversal, n (%) | 2 (3.3%)             | 4 (18.2%)              | 0.02                   |

Values are mean ± SD.

Among the 83 patients in whom coronary flow pattern was recorded, ST resolution was observed at 60 min after reperfusion in 45 patients with good-reflow and in 10 patients with no-reflow (p = 0.02). Absence of ST resolution detected the no-reflow with only 54.5% sensitivity and 73.8% specificity. Peak creatinine kinase-MB value detected the no-reflow with 54.5% sensitivity and 88.5% specificity when 243 IU/L was used as the cut-off point. The area under the curve of peak creatinine kinase-MB was 0.75 ± 0.06, which was significantly smaller than that of diastolic deceleration time (p < 0.0001) (Table 3). A peak creatinine kinase-MB was observed within 15 h after coronary reperfusion in 56 patients (92%) with good-reflow, and in 19 patients (86%) with no-reflow (p = 0.74).

Discussion

We investigated the ability of transthoracic Doppler echocardiography to detect the no-reflow after primary coronary intervention in the 95 patients with anterior wall infarction. Among the 83 patients in whom coronary flow in the left anterior descending artery was recorded, the 22 with no-reflow had significantly smaller systolic peak velocity, higher diastolic peak velocity, shorter diastolic deceleration time and higher incidence of systolic flow reversal than those with good-reflow. Using 185 ms as the cut-off point, diastolic deceleration time detected the no-reflow with 95.5% sensitivity and 95.1% specifici-
coronary angiography and intervention,19 or coronary blood flow was measured before and after intervention.18,19 In these reports, coronary blood flow was measured before intervention was performed only in a small fraction of the subjects.18 In these cases, significant stenosis might not be a reliable index for assessment of the no-reflow phenomenon.

The ability of coronary flow pattern to detect the no-reflow phenomenon

Transthoracic Doppler echocardiography has a limited ability to detect systolic coronary flow velocity even with contrast enhancement.5,7 Antegrade systolic flow was detected in only 61 out of 83 patients (73.4%) in the present study. We could not determine whether the absence of systolic flow in each case was due to systolic flow reduction related with the no-reflow5 or due to technical limitations. Systolic flow reversal would be more difficult to detect than antegrade systolic flow, because it transiently appears in the pre-systole or in the early systole.5 These technical limitations mean that, with systolic peak velocity and the systolic flow reversal, transthoracic Doppler echocardiography fails to detect the no-reflow with sufficient accuracy.

A Doppler guidewire study demonstrated that coronary flow reserve, measured 24 h after coronary intervention, assessed no-reflow after infarction.17 Although the trans-thoracic Doppler technique can measure coronary flow reserve reliably,7 the present study has demonstrated that it could assess no-reflow with excellent accuracy even without unnecessary pharmacological stress.

Prior Doppler echocardiography studies demonstrated that the patients showing TIMI 3 flow at the early stage of myocardial infarction had higher peak diastolic velocity than those with TIMI 2 flow or worse infarction.18,19 In these reports, coronary blood flow was measured before coronary angiography and intervention,19 or coronary intervention was performed only in a small fraction of the subjects.18 In these cases, significant stenosis might remain at the culprit lesion in those showing TIMI flow grade ≤2 and it would attenuate diastolic peak velocity more than systolic peak velocity.20 Diastolic coronary flow did not show attenuation in the patients with no-reflow in the present study because of the absence of significant residual stenosis.

The myocardial contrast echocardiography studies revealed that the no-reflow occurs in about 30% of the patients showing TIMI-3 flow after coronary intervention.2,10,21,22 TIMI flow grade was low sensitivity and high specificity for assessing the no-reflow phenomenon, indicating that improved epicardial coronary flow is essential but not sufficient for good tissue perfusion. TIMI frame count is a quantitative method to assess epicardial coronary flow, and it too failed to assess the no-reflow with sufficient accuracy in the present study. Several reports demonstrated that frame count does not predict mortality after infarction as well as TIMI myocardial perfusion grade,21–23 which also suggests that the frame count might not be a reliable index for assessment of the no-reflow.

Persistent ST-elevation after reperfusion is associated with impaired microvascular reperfusion,24–26 with large infarct size26,27 and with poor clinical outcomes.25 ST resolution was observed even in some with the no-reflow, which resulted in its low sensitivity for assessing the no-reflow in the present study. Santoro et al.28 reported ST resolution, recorded 30 min after successful coronary intervention, predicted no-reflow on the contrast echocardiogram with 77% sensitivity and 91% specificity; these values were higher than those of ST resolution in the present report but still did not match those of deceleration time. ST-elevation gradually reduces after reperfusion even in the patients with the no-reflow,28 and the delayed ECG recording (60 min after coronary intervention) might lower the accuracy of ST resolution in the present study.

Gibson et al.29 reported that creatinine kinase-MB elevation after coronary intervention is 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, creatinine kinase-MB detected the no-reflow better than frame count or ST resolution, though its ability did not match that of deceleration time.

Multiple imputation consists of a three-step process. First, sets of plausible values for missing observations

| Table 3 | Predictive accuracy of parameters to assess the no-reflow phenomenon |
|---------|------------------|------------------|------------------|
|         | Sensitivity (%)  | Specificity (%)  | Area under the curve |
| Systolic peak velocity | 72.7 | 57.4 | 0.63±0.07 |
| Diastolic peak velocity | 81.8 | 55.7 | 0.70±0.07 |
| Diastolic deceleration time | 95.5 | 95.1 | 0.96±0.02 |
| Systolic flow reversal | 18.2 | 96.7 | — |
| TIMI flow grade 2 | 54.5 | 93.4 | — |
| TIMI frame count | 45.5 | 91.8 | 0.64±0.07 |
| Absence of ST resolution | 54.5 | 73.8 | — |
| Peak creatinine kinase-MB | 54.5 | 88.5 | 0.75±0.06 |

The cut-off point of systolic peak velocity used to detect the no-reflow was 6.7cm/s; diastolic peak velocity, 28.5 cm/s; diastolic deceleration time, 185 ms; TIMI frame grade, 52 frames; peak creatinine kinase-MB, 243 IU/L. Area under the curve was determined in the receiver operating characteristic curve and values are mean±standard error.
are created that reflect uncertainty about the non-response model. Each of these sets of plausible values can be used to "fill-in" the missing values and create a "completed" dataset. Then, each of these datasets can be analysed using complete-data methods. Finally, the results are combined, which allows for the uncertainty regarding the imputation to be taken into account. These processes are performed under the assumption of "missing at random". This assumption is mathematically convenient because it allows one to eschew an explicit probability model for non-response. When this assumption is violated, imputation based methods would be biased. Also NORM uses assumption of multivariate normality, but there is some evidence that the inferences tend to be robust to minor departures from this assumption.

Study limitations

We did not investigate the ability of TIMI myocardial perfusion grade to assess the no-reflow, because coronary angiography in some of the present cases did not have the quality suitable for determining TIMI perfusion grade. Further prospective studies may be required to determine the relation between TIMI perfusion grade and the perfusion pattern on contrast echocardiogram.

Myocardial reflow after myocardial infarction could be a complex and dynamic phenomenon to show temporal change after coronary reperfusion. We performed myocardial contrast echocardiography just once because contrast echocardiogram recorded 15 min after reperfusion, as in this report, could predict myocardial infarct size more precisely than those performed later. Repeated contrast echocardiography or coronary blood flow measurement would provide some new insight into the changes in microvascular function.

Though 88% of the success rate of recording coronary flow in the present study was comparable to those in the prior studies, we still could not record coronary flow in some of the patients. We examined the patients in the supine position because they had undergone coronary angiography and coronary intervention using the femoral approach before coronary flow measurement. If patients were placed in the left lateral decubitus position, the success rate could be improved.

References


