Clinical Importance of Microvascular Obstruction on Contrast-Enhanced MRI in Reperfused Acute Myocardial Infarction

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Background The aim of the present study was to investigate the clinical importance of microvascular obstruction (MO) on contrast-enhanced magnetic resonance imaging (MRI), comparing it with the myocardial perfusion index (MPI) assessed using first-pass MRI.

Methods and Results Cardiac MRI was performed in 33 patients within 7 days after reperfusion of a myocardial infarction (MI). Using a bolus injection of Gd-DPTA, first-pass images were obtained with the Turbo-FLASH sequence. Time–intensity curves in the left ventricular cavity and in myocardial sections were generated and then the MPI was assessed by the maximum slope method. Late enhancement (LE) was assessed using the true-FISP sequence. According to the transmurality of LE, the patients were classified into 3 groups: Group 1 included patients with localized endocardial enhancement; Group 2, patients with transmural enhancement; Group 3, patients having LE with MO. In cases of anterior infarction, the MPI for the anterior wall and parts of the inferior wall in Group 3 was significantly lower than that for Group 1 and 2. For inferior infarction, the MPI for parts of the inferior wall in Group 3 was significantly lower than that for Group 1 and 2.

Conclusion MO is related to lower MPI, indicating severe microvascular damage. LE with or without MO is an important marker of perfusion status after reperfused MI. (Circ J 2008; 72: 200–204)

Key Words: Contrast-enhanced MRI; Microvascular obstruction; Myocardial infarction
weighted saturation recovery Turbo-FLASH sequence (repetition time 1.8 ms, echo time 1.2 ms, recovery time after saturation pulse 58 ms, flip angle 8°, field of view 285×300 mm², matrix, 80×128, slice thickness 8 mm, 3 images per 2 heart beats). During an inspiratory breath hold, a bolus of gadopentetate dimeglumine (Magnevist; Schering, Berlin, Germany), 0.1 mmol/kg body weight, was injected into the right antecubital vein at 3 ml/s and flushed with 20 ml of normal saline using a power injector. Next, 60–80 dynamic images were acquired simultaneously during the first and second pass of the contrast agent. The patients were instructed to hold their breath as long as possible and to breathe quietly and slowly when necessary.

Quantification of Myocardial Perfusion Using First-Pass Perfusion Image

A correlation between the contrast-enhanced first-pass myocardial perfusion image and myocardial blood flow has been reported, and we modified the previous quantification of myocardial perfusion using the maximum slope method, which characterizes the relationship between the perfusion and the time–intensity curves of the tissue and arterial input function (AIF). Assuming that extravasation of the contrast media can be neglected during the measurement period, perfusion was estimated according to the following relation presented by Miles et al.

\[ \text{Perfusion} = \frac{\text{maximum initial slope of tissue curve}}{\text{maximum density of the AIF}}. \]

We selected 3 mid-ventricular short-axis slices. Signal intensity (SI) time curves after Gd-DPTA inflow were generated by measuring the SI in elliptical regions of interest (ROI) defined in the left ventricular cavity and in 8 myocardial sections (Fig 1). For all images, an examiner who was unaware of the angiographic results manually traced the ROI, taking care to place the ROI on the myocardium and to exclude the left ventricular cavity, the papillary muscles, and the pericardium. SI time curves were evaluated in the defined myocardial ROI, as well as in the left ventricle (LV), to determine the AIF. In our experimental data, the SI time curves for the LV and the myocardium had maximum up-slopes from the initial inflow in the LV to the following 4 s and from the following 6–10 s (Fig 2). On the basis of the maximum slope method, the myocardial perfusion index (MPI) was defined:

\[ \text{MPI} = \frac{\text{maximum initial slope of the SI of the myocardium}}{\text{the initial upslope of the LV}}. \]

The 8 segments at the mid-ventricular axial-slice were divided into anterolateral, anterior, anteroseptal, septal, inferoseptal, inferior, inferolateral, and lateral. The anterior infarct-related myocardial territory comprised the anterolateral, anterior, and anteroseptal segments. The inferior infarct-related myocardial territory comprised the inferoseptal, and inferior segments (Fig 1). In each case we calculated the MPI for the total 24 segments.

LE Image

LE scans were collected in all short-axis orientations using a breath-hold ECG-triggered 2D inversion recovery true FISP sequence (TR/TE, 2.82/1.41 ms; flip angle, 60°) as described previously. Images were acquired at 10 and 15 min following injection. The inversion time (T1; non-selective inversion pulse) was manually adjusted between 180 and 300 ms to null the signal from normal myocardium. Depending on the field of view, the typical in-plane resolu-
The total imaging time was 25–30 min, which included patient positioning.

**Classification of LE Pattern**

All information on the magnetic resonance (MR) images regarding patient’s identification was obscured and the images were then randomized. Two cardiologists with 25 and 15 years of clinical practice and 2 radiologists with 20 and 15 years of clinical practice visually judged the myocardial enhancement. No information was revealed regarding patient treatment, and disagreements were solved by consensus.

On the basis of the transmurality of LE, patients were classified into 3 groups: Group 1 comprised patients with localized endocardial enhancement; Group 2 was patients with transmural enhancement; and Group 3 comprised patients with LE and endocardial MO (LE+MO). We defined an endocardial hypo-intensity band with a thickness in excess of 2 mm at 15 min following the administration of contrast material as MO.

**Statistical Analysis**

We compared differences in the MPI values between the 2 groups of Groups 1, 2 and Group 3 using the Mann-Whitney U-test. A probability value less than 0.05 was considered statistically significant.

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**Results**

Of the 17 patients with an anterior infarction, there were 6 (38%) in Group 1, 5 (31%) in Group 2, and 5 (31%) in Group 3. Of the 16 patients with an inferior infarction, there were 4 (24%) in Group 1, 7 (41%) in Group 2, and 6 (35%) in Group 3 (Table 1).

**Relationship Between MPI and LE Pattern in Anterior Infarction**

The MPI for anteroseptal and septal (p<0.05) in Group 2 was significantly lower than that for Group 1. The MPI for anterior, anteroseptal, septal, inferior, inferolateral, and anterolateral (p<0.02) in Group 3 was significantly lower than that for Group 1. The MPI for anterior, anteroseptal, inferior, inferoseptal, septal, inferolateral, and anterolateral (p<0.02) in Group 3 was significantly lower than that for Group 2. In cases of anterior infarction, the MPI for the anterior infarct-related territory and parts of the inferior wall in Group 3 was significantly lower than that for Groups 1 and 2 (Fig 5). Representative contrast-enhanced MR images from Group 3 are shown in Fig 6.

**Relationship Between MPI and LE Pattern in Inferior Infarction**

The MPI for inferoseptal in Group 2 (p<0.01) was significantly lower than that for Group 1. The MPI for inferior, inferoseptal, septal, inferior, inferolateral, and anterolateral (p<0.02) in Group 3 was significantly lower than that for Group 2. In cases of inferior infarction, the MPI for the anterior infarct-related territory and parts of the inferior wall in Group 3 was significantly lower than that for Groups 1 and 2 (Fig 7).

**Discussion**

This study summarizes the relationship between LE and first-pass myocardial perfusion on contrast-enhanced MRI.
in acute reperfused MI. The transmural extent of LE correlated strongly with myocardial microvascularity assessed by first-pass perfusion imaging. The MPI for the infarct-related territory with MO was significantly lower than that for the same area without MO, which suggests that LE + MO represents residual MO in the endocardial core of the infarct. Patients with MO might not attain complete reperfusion at the microvascular level, despite successful reperfusion therapy, so LE with or without MO is an important sign of perfusion status after reperfusion therapy. In addition, the MPI for the infarct-related territory in Group 2 was significantly lower than that for Group 1, which suggests that the transmularity of LE without MO is related to the degree of microvascular damage in the infarct-related territory.

In cases of anterior infarction, the MPI for the infarct-related territory, that is, inferoseptal and inferolateral, with MO was significantly lower than without MO. An
anterior infarction with MO affected the reduction in the microcirculation at the periphery of the territory and the decreased MPI in the periphery of the infarction may be caused by a reduction of collateral perfusion through the endocardial microvessels. An anterior infarction with MO represents transmural infarction with broad microvascular damage, including the periphery of the territory. Recent PET studies indicate that restoration of oxidative metabolism in the infarct-related area is more closely related to myocardial damage recovery than perfusion in the early phase after MI. In a comparative assessment of FDG-PET and myocardial perfusion SPECT, preserved myocardial blood flow was more reliable than glucose metabolism in predicting recovery in the reperfused myocardium. However, myocardial metabolism in LE with or without MO is not well understood and we intend following the present cases for the long-term in order to clarify the predictive value of MO for LV functional recovery.

As shown in Fig. 6, the 2-phase images on contrast-enhanced MRI show a perfusion defect and MO in the anterior wall. However, the alteration in myocardial blood flow in the non-infarct area, that is, the inferior wall, was not evaluated by visualization. In the present study, the combination of MPI and LE could reveal a reduction in blood flow in the non-infarct-related territory, such as the inferior wall in an anterior infarction. It is unlikely that such regions would be detectable without adenosine vasodilatation.

The combinative analysis of 2-phase contrast-enhanced MRI has the possibility of non-invasively detecting reduced blood flow in viable myocardium at rest.

Study Limitations

Because the present study was limited to the relatively short period after MI, we are not speculating the predictive value of MO for long-term prognosis. In addition, our results must be interpreted in the light of a potential selection bias in the study patients. The clinical course after an infarct may be modified beneficially by early reperfusion. Thus, it seems difficult to directly compare our results with those of chronic MI and non-reperfused MI.

On the first-pass perfusion images, the baseline intensity in the myocardium tended to be high in the septum and low in the inferior wall, and similarly for the MPI for Group 1 (Figs 5, 7). Different signal intensities were gained from the anterior and inferior myocardial regions because the surface coil was used for image acquisition. In addition, the high intensity in the septal wall may be affected by contrast in the right ventricular cavity. MPI might have regional variations caused by surface coil effects and the partial volume effects of right ventricular intensity.

Conclusion

MO is related to a lower MPI, indicating severe microvascular damage. LE with or without MO is an important predictor of perfusion status after reperfusion therapy. Anterior infarction with MO suggests broad microvascular damage including the periphery of the territory.

References