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Invasive Physiologic Assessment of Myocardial Viability After Primary Angioplasty in Acute Myocardial Infarction: Comparison With FDG–PET Imaging
Invasive Physiologic Assessment of Myocardial Viability After Primary Angioplasty in Acute Myocardial Infarction: Comparison With FDG–PET Imaging

by

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A Dissertation Submitted to The Graduate School of Ajou University in Partial Fulfillment of the Requirements for the Degree of

DOCTOR OF PHILOSOPHY

Supervised by

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Department of Medical Sciences

The Graduate School, Ajou University

February, 2007
林弘錫의 醫學 博士學位 論文을 認准함.

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審査委員 具 本 權 印

亞洲大學校大學院

2006年 12月 22日
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Finally, I would like to thank God and want to acknowledge the tremendous moral support and contributions of my parents, my sister, my wife and my lovely daughter and son.

I would like to dedicate this manuscript to my wife and my kids.

October 2006
Hong-Seok Lim
Invasive Physiologic Assessment of Myocardial Viability After Primary Angioplasty in Acute Myocardial Infarction: Comparison With FDG–PET Imaging

Background & purpose: The state of coronary microcirculation is an important determinant of myocardial viability and clinical outcomes in acute myocardial infarction (AMI). However, to date, there has been lacking in comparative studies on the most reliable invasive, on–site measurement for assessing the microvascular integrity and myocardial viability in AMI. The aim of this study is to evaluate the usefulness of coronary physiologic parameters as a predictor for myocardial viability after primary percutaneous coronary intervention (PCI) in AMI.

Materials & Methods: Nineteen patients (17 male, mean age 60±13 years) underwent primary PCI for AMI (LAD:13, RCA:5, LCX:1) were enrolled. After successful PCI, Doppler–derived coronary flow reserve (CFR\textsubscript{Doppler}), microvascular resistance index (MVRI) and phasic coronary flow velocity patterns were evaluated. Using a pressure–temperature sensor–tipped coronary wire, thermodilution–derived CFR (CFR\textsubscript{thermo}), fractional flow reserve (FFR) and coronary wedge pressure (P\textsubscript{cw}) were measured and the ratio of P\textsubscript{cw} and mean aortic pressure (P\textsubscript{cw}/P\textsubscript{a}) was calculated, along with index of microcirculatory resistance (IMR), defined as the distal coronary
pressure divided by the inverse of the hyperemic mean transit time. 

$^{18}$F-fluorodeoxyglucose (FDG) PET was performed after primary PCI in 7 days to evaluate myocardial viability by regional percentage uptake of FDG in infarct-related segments.

**Results**: Among Doppler-derived parameters, regional FDG-uptake was associated with baseline average peak velocity (bAPV) ($r=0.530, p=0.020$), hyperemic APV (hAPV) ($r=0.675, p=0.002$) and hyperemic MVRI (hMVRI) ($r=-0.534, p=0.018$). All parameters derived from phasic coronary flow velocity patterns showed good correlations with regional FDG-uptake (baseline deceleration time of diastolic flow velocity (bDDT), $r=0.533, p=0.019$; hyperemic DDT (hDDT), $r=0.513, p=0.025$; systolic bAPV (bSAPV), $r=0.592, p=0.008$). In the group of coronary pressure measurements, a fair correlations existed between IMR, $P_{cw}/P_{a}$ and regional FDG uptake ($r=-0.660, p=0.002$; $r=-0.601, p=0.007$, respectively). Regional FDG uptake had no association with CFR$_{Doppler}$, CFR$_{thermo}$, FFR and $P_{cw}$. The largest area under receiver operating characteristics (ROC) curve was acquired by the analysis between IMR and myocardial viability as defined by the 50% FDG PET threshold value (0.856, 95% CI [0.620–0.970]). Cut-off value of IMR for the prediction of myocardial viability was 22 (sensitivity of 78%, specificity of 90% and accuracy of 86%).

**Conclusions**: Coronary physiologic assessment provides useful informations for the prediction of myocardial viability immediately after primary PCI. IMR, a novel index representing the microvascular integrity, is a reliable parameter for the invasive, on-site assessment of myocardial viability.
viability after primary PCI in AMI.

**Key Words**: myocardial viability, acute myocardial infarction, microvascular integrity, index of microcirculatory resistance, FDG–PET
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AMI = acute myocardial infarction
CFR = coronary flow reserve
DDT = deceleration time of diastolic flow velocity
FDG-PET = 18F-Fluorodeoxyglucose positron emission tomography
FFR = fractional flow reserve
IMR = index of microcirculatory resistance
PCI = percutaneous coronary intervention
Pcw/Pa = coronary wedge pressure/mean aortic pressure
TMPG = TIMI myocardial perfusion grade
TIMI = thrombolysis in myocardial infarction
T_{mn} = mean transit time
I. INTRODUCTION

A. BACKGROUND

Assessment of myocardial viability is important to predict functional recovery and future cardiac events in patients with acute myocardial infarction (AMI) (Bonow et al., 1996; Dislizian et al., 1996; Di Carli et al., 1994), and microvascular function and integrity are the most important determinants of myocardial viability, left ventricular (LV) function and prognosis after AMI (Ito et al., 1992; Kondo et al., 1998; Maes et al., 1995). However, to date, a reliable invasive method for the on-site assessment of the coronary microcirculation has been lacking. Current methods for evaluating the status of the microcirculation are limited because they are qualitative, are cumbersome, rely on sophisticated analyses, or do not independently interrogate the microcirculation (Gibson et al., 2000; Uren et al., 1994; Yeung et al., 1998; Ito et al., 1992; Kern, 2000). Furthermore, many techniques are noninvasive and not readily applicable in the cardiac catheterization laboratory, where many patients first present for evaluation of their coronary circulation (Topol et al., 1993).

Guidewire-based measurement of coronary flow reserve (CFR), either by Doppler flow or thermodilution techniques, has become an increasingly important invasive method for assessing the physiological significance of coronary disease (Kern, 2000; Fearon et al., 2003). However, use of CFR to interrogate the microcirculation independently is limited because CFR interrogates the flow status of both the epicardial artery and the...
microcirculation but does not allow discrimination between these 2 components (Kern, 2000). Furthermore, CFR is limited by its dependence on heart rate and blood pressure, thereby calling into question its reproducibility (De Bruyne et al., 1996).

With recent technological advances, it is now possible to measure pressure and to estimate coronary artery flow simultaneously with a single pressure-temperature sensor-tipped coronary wire (De Bruyne et al., 2001; Pijls et al., 2002). By the thermodilution technique, the mean transit time \(T_{mn}\) of room-temperature saline injected down a coronary artery can be determined and has been shown to correlate inversely with absolute flow (De Bruyne et al., 2001). From this technique, a thermodilution-based CFR (CFR_{thermo}) can be derived that has been shown to correlate well with Doppler velocity wire-derived CFR (CFR_{Doppler}) and with absolute flow as measured by a flow probe but that has the same conceptual disadvantages as CFR_{Doppler} (Fearon et al., 2003; Pijls et al., 2002). Using this thermodilution method, a novel index of microcirculatory resistance (IMR) was proposed and validated for assessing the status of the microcirculation independent of the epicardial artery (Fearon et al., 2003). In an animal model, IMR, defined as the distal coronary pressure divided by the inverse of the hyperemic mean transit time \((hT_{mn})\), correlated well with an accepted experimental method for measuring microvascular resistance (Fearon et al., 2003). Unlike CFR, IMR is derived at peak hyperemia, thereby eliminating the variability of resting vascular tone and hemodynamics (Fearon et al., 2003).

Angiographic and other physiologic parameters including TIMI myocardial
perfusion grade (TMPG), deceleration time of diastolic flow velocity (DDT), hyperemic microvascular resistance index (hMVRI), pressure-derived collateral flow index (CFIb) and coronary wedge pressure to mean aortic pressure ratio (Pcw/Pa) also have been known as useful indices which may represent myocardial viability and microvascular integrity after AMI (Maes et al., 1995; Neumann et al., 1997; Meuwissen et al., 2001; Yamamoto et al., 2001).

Positron emission tomography (PET), with high spatial resolution, high-count-density images, and the possibility for attenuation correction, allows accurate assessment of regional uptake using fluorine-18-labeled fluorodeoxyglucose (FDG) in different patient, and is now considered to be one of the 'gold standard' tests of myocardial viability (Saha et al., 1996; Udelson et al., 1998). Also, PET imaging with FDG has been widely used to assess myocardial viability in patients with myocardial infarction because it has provided accurate information concerning differentiating reversibly ischemic myocardium from irreversible scar tissue (Marshall et al., 1983; Schwaiger et al., 1986; Tamaki et al., 1995).

B. OBJECTIVES

Although many invasive coronary physiologic parameters have been introduced for assessing microvascular integrity and myocardial viability, it is unclear whether the parameters also correlates with quantitative evaluation by PET in AMI. Also, a novel IMR may reflect microvascular integrity and may increase after AMI. However, its exact relation with...
residual myocardial viability following reperfusion is unclear. The goal of
the present study was to evaluate the value of invasive coronary
physiologic parameters including IMR for the assessment of microvascular
integrity and myocardial viability in patients with AMI after primary PCI by
direct comparison with quantitative metabolic PET imaging with FDG.
II. MATERIALS and METHODS

A. SUBJECTS

The study population comprised 19 patients with the diagnosis of a first AMI who underwent primary PCI within 24 hours after the onset of symptoms. The study inclusion criteria were as follows: (1) first AMI, (2) successful recanalization with primary PCI (defined as residual stenosis ≤ 25% visually) within 24 hours after the onset of symptoms, and (3) informed consent to perform primary PCI and coronary physiologic measurement. The diagnosis of AMI was based on > 30 minutes of continuous chest pain, ST elevation > 2.0 mm in ≥ 2 contiguous ECG leads, a > 3-fold increase over the normal value in serum creatine kinase (CK) with increased MB fraction, and Thrombolysis In Myocardial Infarction (TIMI) flow grade 0, 1, or 2 at initial coronary angiography. Patients were excluded if any one of the following was present: prior myocardial infarction (MI), cardiogenic shock, left main disease, culprit lesion located at distal coronary artery, significant arrhythmia rendering an invasive coronary physiologic study inappropriate.

B. PROCEDURE

On admission, all patients were pretreated with aspirin (300 mg) and clopidogrel (300–600 mg). An intravenous infusion of heparin was started (1,000 U/h) after a 5,000 U intravenous bolus injection before angiography,
and 0.5 mg/kg/min of nitroglycerin was continuously given intravenously soon after establishment of the diagnosis. Diagnostic coronary angiography was performed via the femoral approach by use of the Judkins technique. Coronary angioplasty with stenting was performed and activated clotting time was maintained over 300 seconds during the procedure with an additional intravenous or intra-arterial bolus injection of heparin. An angiographic criterion of ≤ 25% residual stenosis was accepted as successful results of the procedure. After successful angioplasty, coronary physiologic parameters were measured with Doppler wire (FloWire, Cardiometrics, Mountain View, CA, USA) and pressure wire (Radi Medical Systems, Uppsala, Sweden). CK was measured serially every 3 hours after recanalization until the peak value was obtained. Patients received conventional drug therapy according to individual need, which was determined by the attending physician. The stented patients received antiplatelet treatment with a clopidogrel and aspirin regimen (clopidogrel 75 mg and aspirin 100 mg a day). All patients underwent FDG–PET imaging for assessing myocardial viability in 7 days after primary PCI.

C. ANALYSIS OF CORONARY ANGIOGRAM

All cineangiogram were reviewed, and analyzed with a computer–assisted, automated edge detection algorithm (Philips Medical System, Eindhoven, Netherlands). Percent diameter stenosis of the culprit lesion were quantitatively analyzed offline from a cineangiogram taken primary PCI. Contrast flow through the infarct–related coronary artery was
graded by the standard TIMI flow scale of 0 to 3 from the final coronary angiogram (Topol, 2003). TIMI myocardial perfusion grade (TMPG) was evaluated with scale of 0 to 3 from the final coronary angiogram after PCI (Gibson et al., 2000). Collateral flow was graded according to the Rentrop classification of 0 to 3 from the initial coronary angiogram (Rentrop et al., 1985).

D. INTRACORONARY DOPPLER FLOW MEASUREMENTS

Coronary flow velocities were recorded in the epicardial coronary artery distal to the culprit lesion where there was neither a significant stenosis nor a large side branch angiographically, to assess coronary blood flow to the entire area at risk by using a 0.014-in (0.035-cm), 12-MHz Doppler guide wire (FloWire, Cardiometrics, Mountain View, CA, USA) and a velocimeter (FloMap, Cardiometrics, Inc.) following successful primary PCI, as described previously (Doucette et al., 1992; De Bruyne et al., 1996). The tip of the guide wire was placed precisely at the distal to the coronary lesion, and an optimal Doppler signal was obtained by moving the guide wire slightly within the vessel lumen and adjusting the range gate control. The final position of the Doppler guide wire was confirmed by contrast injection. During the Doppler study, an electrocardiogram (ECG) and pressure waveform at the tip of the guiding catheter were monitored continuously. Frequency analysis of the Doppler signals was carried out in real time by fast Fourier transform, using the Doppler velocimeter (Doucette et al., 1992). Five minutes after contrast injection, Doppler signals were
recorded on videotape and by a video printer at a sweep speed of 100 mm/s, along with an ECG and aortic pressure tracing. The time average of the instantaneous spectral peak velocity (time-averaged peak velocity, APV) during one cardiac cycle was measured from the phasic coronary flow velocity recordings (Doucette et al., 1992). CFR\textsubscript{Doppler} was obtained by the ratio of intravenous adenosine (140μg/kg/min)–induced maximal hyperemia to baseline resting APV (Klocke et al., 1987; Marcus et al., 1981; Hoffman et al., 1984). The coronary blood flow velocity spectrum recorded on a Super VHS videotape was digitized by offline computerized planimetry. The digitized coronary blood flow velocity spectrum provided the following parameters: APV, average systolic peak velocity (cm/s; SAPV) and deceleration time of diastolic flow velocity (ms; DDT). These parameters were measured in 3 consecutive cardiac cycles and averaged for the mean value. The hyperemic microvascular resistance index (hMVRI) was determined as the ratio of mean distal coronary artery pressure to APV during maximal hyperemia.

E. INTRACORONARY PRESSURE MEASUREMENTS

A 0.014–in fiber optic pressure monitoring guide wire (Radi Medical System, Uppsala, Sweden) was calibrated, equalized to the guiding catheter pressure with the sensor positioned at the ostium of the coronary artery, and then advanced to the distal to culprit lesion (at least two thirds of the way down the vessel). CFR\textsubscript{thermo}, IMR, and fractional flow reserve (FFR) were measured by methods described previously (Fearon et al., 2003;
Fearon et al., 2003). Briefly, with commercially available software (Radi Medical Systems), the shaft of the pressure wire can act as a proximal thermistor by detecting changes in temperature–dependent electrical resistance. The sensor near the tip of the wire simultaneously measures pressure and temperature and can thereby act as a distal thermistor. The transit time of room-temperature saline injected down a coronary artery can be determined with a thermodilution technique (De Bruyne et al., 2001; Pijls et al., 2002). Three injections of 3 mL of room-temperature saline were made down the coronary artery, and the baseline mean transit time ($bT_{mn}$) was measured. Intravenous infusion of adenosine (140 $\mu$g/kg/min) was then administered to induce steady state maximal hyperemia, and 3 more injections of 3 mL of room-temperature saline were made, and the hyperemic mean transit time ($hT_{mn}$) was measured. Simultaneous measurements of mean aortic pressure ($P_a$, by guiding catheter) and mean distal coronary pressure ($P_d$, by pressure wire) were also made in the resting and maximal hyperemic states. $\text{CFR}_{\text{thermo}}$ was calculated as $bT_{mn}$ divided by $hT_{mn}$. IMR was calculated as $P_d$ at maximal hyperemia divided by the inverse of the $hT_{mn}$. $\text{FFR}$ was calculated by the ratio of $P_d/P_a$ at maximal hyperemia.

In resting baseline state after primary PCI, the culprit lesion was occluded by the inflated balloon to measure distal coronary artery wedge pressure ($P_{cw}$) with simultaneous measurement of $P_a$ via the guiding catheter. The ratio of $P_{cw}$ to $P_a$ ($P_{cw}/P_a$) was calculated as $P_{cw}$ divided by $P_a$.

**F. FDG PET PROCEDURE**
In all studied patients, FDG PET was conducted (at 6.4±1.7 days) as a standard reference for detecting viable myocardium, using a whole-body PET scanner (Discovery ST scanner, General Electric Medical Systems, Milwaukee, WI, USA). All patients, who had fasted for at least 4 hours, were administered 50 g of glucose orally and 4 IU of insulin subcutaneously 40 min before FDG injection to promote FDG uptake. Plasma glucose, free fatty acids and insulin levels were checked 30 min before FDG injection. When the plasma glucose level was not appropriate, patients were administered a rescue dose of glucose or insulin to stabilize the substrate environment. CT-based attenuation correction was performed followed by intravenous administration of approximately 370 MBq of FDG. Image data were recorded with a 256×256 matrix in 3 consecutive bed positions over 15 min per position. The data were reconstructed and backprojected with a Hanning filter (5mm).

For the analysis of FDG-PET images, a 20-segment scoring system was used (Hachamovitch et al., 1998). In short, according to this system three short-axis slices (apical, mid and basal) are divided into six segments each and two segments represent the apex (Fig. 1). Each of the segments has a distinct number, as indicated in Fig. 1. For regional analysis, the anterior region is defined by segments 1, 7 and 13, the septal region by segments 2, 3, 8, 9, 14 and 15, the inferior region by segments 4, 10 and 16, the lateral region by segments 5, 6, 11, 12, 17 and 18 and the apex by segments 19 and 20. The regions of interest (ROIs) method was used to evaluate the FDG uptake in infarct-related segments. The segmental
activities were expressed as a percentage of maximum uptake (Sutter et al., 2000). The regional percentage uptake of FDG in the segments on the PET images were calculated and compared. According to a previous report, myocardial segments were defined viable by FDG–PET if the regional FDG–uptake was $\geq 50\%$ in a normally perfused segment with normal wall motion (Segall et al., 2002).
**Fig. 1.** Diagrammatic representation of the 20-segment model of FDG-PET imaging: For regional analysis, the anterior region is defined by segments 1, 7 and 13, the septal region by segments 2, 3, 8, 9, 14 and 15, the inferior region by segments 4, 10 and 16, the lateral region by segments 5, 6, 11, 12, 17 and 18 and the apex by segments 19 and 20.
G. STATISTICAL ANALYSIS

Data are presented as means ± standard deviations for continuous variables and frequency for categorical variables. Comparisons of continuous variables were performed using Student t test. Analyses of categorical variables were performed using the chi-square test or Fisher's exact test where appropriate. Pearson's correlation analysis was employed to examine the relationship of coronary physiologic parameters to regional FDG-uptake of infarct-related segments. The receiver operating characteristic curve (ROC) was employed to compare the area under ROC of physiologic parameters for the prediction of myocardial viability as defined by the 50% FDG PET threshold value and to determine the best cut-off value of IMR for the prediction of myocardial viability. All statistical analyses were performed using SPSS version 13.0 (SPSS Inc., Chicago, Illinois), and a p value of < 0.05 was considered statistically significant.
III. RESULTS

A. PATIENTS CHARACTERISTICS

Clinical characteristics are presented in Table 1. The study population consisted of 19 patients (17 men and 2 women) with a mean age of 60±13 years. All had received primary PCI at time of admission. The patients were classified into two groups according to the result of FDG PET imaging. 'PET-viable' group is consisted with patients showed regional FDG-uptake $\geq$ 50%, and the patients in 'PET-nonviable' group had regional FDG-uptake $<$ 50%. The mean regional FDG-uptake was 49.8±12.6%. Regional FDG-uptake was 40.3±6.5% in 'PET-nonviable' group and 60.4±8.4% in 'PET-viable' group. The culprit vessel was located with similar frequency in both groups. The onset to reperfusion time (min) was lower in 'PET-viable' group than 'PET-nonviable' group (267±117 vs. 457±217, $p<0.047$). The mean LV ejection fraction (EF) was 52±11% and 'PET-nonviable' group had lower EF than in 'PET-viable' group (47±9 vs. 58±10%, $p=0.021$). Collateral flow grade was not different between groups. Percentage of TMPG 3 achievement in final angiogram after primary PCI was higher in 'PET-viable' group than in 'PET-nonviable' group (44 vs. 10%, $p=0.018$).
### Table 1. Clinical, angiographic and FDG–PET characteristics

<table>
<thead>
<tr>
<th></th>
<th>'PET-viable' group (n = 9)</th>
<th>'PET-nonviable' group (n = 10)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, y</td>
<td>52±10</td>
<td>59±12</td>
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<tr>
<td>Male</td>
<td>8 (89%)</td>
<td>9 (90%)</td>
<td>0.941</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>58±10</td>
<td>47±9</td>
<td>0.021</td>
</tr>
<tr>
<td>Results of reperfusion</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak CK, IU</td>
<td>2005±1967</td>
<td>2705±1462</td>
<td>0.388</td>
</tr>
<tr>
<td>Time to reperfusion, min</td>
<td>267±117</td>
<td>457±217</td>
<td>0.047</td>
</tr>
<tr>
<td>Coroanry angiographic findings</td>
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<td></td>
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<tr>
<td>Culprit vessel</td>
<td>6 / 3 / 0</td>
<td>7 / 1 / 2</td>
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<td>Location of occlusion</td>
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<td></td>
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<td>Proximal</td>
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<td></td>
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<tr>
<td>Mid</td>
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<td>2</td>
<td></td>
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<tr>
<td>% DS after PCI</td>
<td>6.5±2.3</td>
<td>11.1±2.2</td>
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<tr>
<td>Collateral flow before PCI(%)</td>
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<td>0.928</td>
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<tr>
<td>Grade 0</td>
<td>5 (56)</td>
<td>5 (50)</td>
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</tr>
<tr>
<td>Grade 1</td>
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<td>3 (30)</td>
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<td>2 (22)</td>
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<tr>
<td>Grade 3</td>
<td>0 (0)</td>
<td>0 (0)</td>
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</tr>
<tr>
<td>TMP grade after PCI(%)</td>
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<td>0.018</td>
</tr>
<tr>
<td>Grade 0</td>
<td>0 (0)</td>
<td>3 (30)</td>
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<tr>
<td>Grade 1</td>
<td>0 (0)</td>
<td>4 (40)</td>
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</tr>
<tr>
<td>Grade 2</td>
<td>5 (56)</td>
<td>2 (20)</td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>4 (44)</td>
<td>1 (10)</td>
<td></td>
</tr>
<tr>
<td>Regional FDG-uptake, %</td>
<td>60.4±8.4</td>
<td>40.3±6.5</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

DS = diameter stenosis; LAD = left anterior descending artery; LCx = left circumflex artery; LVEF = left ventricular ejection fraction at admission; Peak CK = peak creatine kinase; PCI = percutaneous coronary intervention; RCA = right coronary artery; TMP = TIMI myocardial perfusion.
B. RELATIONSHIPS BETWEEN INTRACORONARY DOPPLER MEASUREMENTS AND FDG-UPTAKE

Intracoronary Doppler measurements are presented in Table 2. In the group of flow velocity parameters hyperemic APV (hAPV) were higher in 'PET-viable' group (25.8±10.2 vs. 39.6±16.7 cm/s, p=0.043). hMVRI tended to be lower in 'PET-viable' group but there was no statistical difference between 2 groups (2.7±1.3 vs. 4.1±2.6 mmHg cm⁻¹ s⁻¹, p=0.134). baseline APV (bAPV) and CFRDoppler were higher in 'PET-viable' group without statistical differences (19.2±7.6 vs. 15.7±5.1 cm/s, p=0.254; 2.1±0.6 vs. 1.7±0.5, p=0.058, respectively). Among the phasic coronary flow velocity patterns, baseline DDT (bDDT) were higher in 'PET-viable' group (660±211 vs. 416±227 ms, p=0.027). Baseline SAPV (bSAPV) demonstrated no differences between 2 groups (12.2±4.4 vs. 9.1±4.5 cm/s, p=0.145). CFRDoppler did not correlate well with regional FDG-uptake, but bAPV, hAPV showed good correlation with regional FDG-uptake (r=0.390, p=0.099; r=0.530, p=0.020; r=0.675, p=0.002, respectively) (Fig. 2). hMVRI inversely correlated with regional FDG-uptake (r=-0.534, p=0.018) (Fig. 2). All parameters derived from phasic coronary flow velocity pattern recordings significantly correlated with regional FDG-uptake (bDDT, r=0.533, p=0.019; hDDT, r=0.513 p=0.025; bSAPV, r=0.592, p=0.008) (Fig. 2).
**Table 2. Intracoronary Doppler measurements**

<table>
<thead>
<tr>
<th></th>
<th>'PET–viable' group (n = 9)</th>
<th>'PET–nonviable' group (n = 10)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Flow velocity parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>APV, cm/s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>19.2±7.6</td>
<td>15.7±5.1</td>
<td>0.254</td>
</tr>
<tr>
<td>Hyperemia</td>
<td>39.6±16.7</td>
<td>25.8±10.2</td>
<td>0.043</td>
</tr>
<tr>
<td>CFR&lt;sub&gt;Doppler&lt;/sub&gt;</td>
<td>2.1±0.6</td>
<td>1.7±0.5</td>
<td>0.058</td>
</tr>
<tr>
<td><strong>Phasic flow velocity patterns</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bSAPV, cm/s</td>
<td>12.2±4.4</td>
<td>9.1±4.5</td>
<td>0.145</td>
</tr>
<tr>
<td>bDDT, ms</td>
<td>660±211</td>
<td>416±227</td>
<td>0.027</td>
</tr>
<tr>
<td>hMVRI, mmHg·cm⁻¹·s</td>
<td>2.7±1.3</td>
<td>4.1±2.6</td>
<td>0.134</td>
</tr>
</tbody>
</table>

APV = averaged peak velocity; bDDT = baseline deceleration time of diastolic flow velocity; bSAPV, baseline systolic averaged peak velocity; CFR<sub>Doppler</sub> = Doppler-derived coronary flow reserve; hMVRI = hyperemic microvascular resistance index.
A. Relationship between flow velocity parameters and FDG uptake

- $r = 0.530$, $p = 0.020$

- $r = 0.675$, $p = 0.002$

- $r = 0.390$, $p = 0.099$

- $r = -0.534$, $p = 0.018$
B. Relationship between phasic coronary flow velocity patterns and FDG uptake

**Fig. 2.** Correlation between intracoronary Doppler measurements and regional FDG-uptake. Regional FDG uptake is plotted against baseline average peak velocity (bAPV), hyperemic average peak velocity (hAPV), Doppler-derived coronary flow reserve (Doppler CFR), hyperemic microvascular resistance index (hMVRI), baseline deceleration time of diastolic flow velocity (bDDT), hyperemic deceleration time of diastolic flow velocity (hDDT) and baseline systolic average peak velocity (bSAPV) in A and B. Correlation coefficients are shown.
C. RELATIONSHIPS BETWEEN INTRACORONARY PRESSURE MEASUREMENTS AND FDG-UPTAKE

Intracoronary pressure measurements are presented in Table 3. Pa and Pd were similar in both groups at baseline and maximal hyperemia. $hT_{mm}$ was longer in 'PET-nonviable' group than in 'PET-viable' group ($0.60\pm0.41$ vs. $0.20\pm0.10$sec, $p=0.016$). There were no differences of $CFR_{thermo}$, FFR and Pcw/Pa between 'PET-viable' and 'PET-nonviable' group. IMR was higher in 'PET-nonviable' group than in 'PET-viable' group ($51.1\pm36.7$ vs. $18.7\pm12.4$ U, $p=0.023$). CFR$_{thermo}$ and FFR did not show significant correlations with FDG-uptake(Fig. 3). A Significant inverse correlation was found between IMR and FDG-uptake ($r=-0.660$, $p=0.002$)(Fig. 4), and Pcw/Pa inversely correlated with FDG-uptake ($r=-0.601$, $p=0.007$)(Fig. 3).
**Tabel 3. Intracoronary pressure wire measurements**

<table>
<thead>
<tr>
<th></th>
<th>'PET-viable' group (n = 9)</th>
<th>'PET-nonviable' group (n = 10)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pa, mmHg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>97±9</td>
<td>95±18</td>
<td>0.716</td>
</tr>
<tr>
<td>Hyperemia</td>
<td>93±13</td>
<td>92±17</td>
<td>0.916</td>
</tr>
<tr>
<td>Pd, mmHg</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>92±6</td>
<td>92±18</td>
<td>0.991</td>
</tr>
<tr>
<td>Hyperemia</td>
<td>88±14</td>
<td>86±17</td>
<td>0.798</td>
</tr>
<tr>
<td>T_{mn}, s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline</td>
<td>0.58±0.45</td>
<td>1.00±0.49</td>
<td>0.069</td>
</tr>
<tr>
<td>Hyperemia</td>
<td>0.20±0.10</td>
<td>0.60±0.41</td>
<td>0.016</td>
</tr>
<tr>
<td>CFR_{thermo}</td>
<td>2.7±1.1</td>
<td>2.0±0.8</td>
<td>0.130</td>
</tr>
<tr>
<td>FFR</td>
<td>0.94±0.36</td>
<td>0.95±0.27</td>
<td>0.121</td>
</tr>
<tr>
<td>Pcw, mmHg</td>
<td>27±10</td>
<td>30±11</td>
<td>0.622</td>
</tr>
<tr>
<td>Pcw/Pa</td>
<td>0.27±0.08</td>
<td>0.34±0.09</td>
<td>0.092</td>
</tr>
<tr>
<td>IMR (U)</td>
<td>60.4±8.4</td>
<td>40.3±6.5</td>
<td>0.023</td>
</tr>
</tbody>
</table>

CFR_{thermo} = thermodilution coronary flow reserve; FFR = fractional flow reserve; IMR = index of microcirculatory resistance; Pa = mean aortic pressure; Pcw = coronary wedge pressure; Pcw/Pa = coronary wedge pressure to mean aortic pressure ratio; Pd = mean distal coronary artery pressure; T_{mn} = mean transit time.
A. Relationship between CFRthermo, FFR and FDG uptake

![Graphs showing correlations between CFRthermo, FFR, and FDG uptake.](image)

- $r = 0.414$, $p = 0.078$
- $r = -0.066$, $p = 0.788$

B. Relationship between Pcw, Pcw/Pa and FDG uptake

![Graphs showing correlations between Pcw, Pcw/Pa, and FDG uptake.](image)

- $r = -0.347$, $p = 0.145$
- $r = -0.601$, $p = 0.007$

**Fig. 3.** Correlation between intracoronary pressure wire measurements and FDG-uptake. Regional FDG uptake is plotted against thermodilution coronary flow reserve (CFRthermo), fractional flow reserve (FFR), coronary wedge pressure (Pcw) and Pcw to mean aortic pressure (Pa) ratio (Pcw/Pa) in A and B. Correlation coefficients are shown.
Fig. 4. Correlation between index of microcirculatory resistance (IMR) and FDG-uptake.
D. COMPARISON OF PHYSIOLOGIC PARAMETERS FOR THE ASSESSMENT OF MYOCARDIAL VIABILITY

Area under receiver operating characteristic (ROC) curve of coronary physiologic parameters which had significant correlation with regional FDG uptake by univariate analysis, for the assessment of myocardial viability as defined by the 50% FDG PET threshold was compared. The largest area under ROC curve was acquired by analysis between IMR and myocardial viability (0.856, 95% CI [0.620–0.970]) (Table 4).
**Table 4.** Comparison of ROC curve analysis of physiologic parameters for the prediction of myocardial viability as defined by the 50% FDG PET threshold value.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Area under ROC</th>
<th>SE</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>bAPV</td>
<td>0.689</td>
<td>0.125</td>
<td>[0.439–0.877]</td>
</tr>
<tr>
<td>hAPV</td>
<td>0.756</td>
<td>0.115</td>
<td>[0.508–0.919]</td>
</tr>
<tr>
<td>hMVRI</td>
<td>0.700</td>
<td>0.122</td>
<td>[0.450–0.884]</td>
</tr>
<tr>
<td>bDDT</td>
<td>0.789</td>
<td>0.109</td>
<td>[0.544–0.938]</td>
</tr>
<tr>
<td>bSAPV</td>
<td>0.678</td>
<td>0.126</td>
<td>[0.428–0.869]</td>
</tr>
<tr>
<td>Pcw/Pa</td>
<td>0.672</td>
<td>0.126</td>
<td>[0.423–0.865]</td>
</tr>
<tr>
<td>IMR</td>
<td>0.856</td>
<td>0.089</td>
<td>[0.620–0.970]</td>
</tr>
</tbody>
</table>

bAPV = baseline average peak velocity (APV); hAPV = hyperemic APV; bDDT = baseline deceleration time of diastolic flow velocity; bSAPV = baseline systolic average peak velocity; CI = confidence interval; hMVRI = hyperemic microvascular resistance index; IMR = index of microcirculatory resistance; Pcw/Pa = coronary wedge pressure to mean aortic pressure ratio; SE = standard error
E. CUT-OFF VALUE OF IMR FOR THE PREDICTION OF MYOCARDIAL VIABILITY

Receiver operating characteristic (ROC) curve analysis showed that an adequate cut-off value of IMR for the prediction of myocardial viability as defined by the 50% FDG PET threshold value was 22 with sensitivity of 78%, specificity of 90% and accuracy of 86% (Fig. 5).
Fig. 5. Plot of the receiver operating characteristic (ROC) curve for adequate cut-off value of index of microcirculatory resistance (IMR) for the prediction of myocardial viability as defined by the 50% FDG PET threshold value. The best cut-off value (BCV) of IMR is 22U and the area under the ROC curve (AUC) is 0.86±0.09.
IV. DISCUSSION

In many patients with coronary artery disease, including AMI presenting to the cardiac catheterization laboratory, the status of the coronary microcirculation, not just the epicardial arteries, is of clinical and prognostic relevance (Chilian et al., 1997). However, to date, there is no specific, and reproducible invasive measure of the status of the coronary microcirculation. The present study demonstrated that which parameters among coronary physiologic measurements using intracoronary Doppler and pressure wire could be a predictor in the assessment of microvascular integrity and myocardial viability in patients with AMI treated with primary PCI. In particular, various coronary physiologic parameters, which are currently available in the clinical field, were measured simultaneously in the same clinical conditions. The salient findings of the present study are as follows: (1) IMR demonstrates strong inverse correlation with myocardial viability in AMI patients after primary PCI, and (2) whereas CFR, FFR and Pcw is not representative for myocardial viability in this patients population. Furthermore, phasic coronary flow velocity patterns and Pcw/Pa are also useful for the estimation of myocardial viability in patients with AMI after primary PCI. These findings suggest that in the group of intracoronary pressure measurements, IMR could be reliably applied in the catheterization laboratory for interrogation of microcirculatory resistance and prediction of myocardial viability. Furthermore, simultaneous measurement of Pcw/Pa with a single pressure-temperature sensor-tipped coronary wire may provide an additional informations for comprehensive and specific
assessment of coronary physiology at microvascular levels in acute stage of MI after reperfusion. Among intracoronary Doppler measurements, phasic coronary flow velocity patterns and hMVRI could be useful to assess myocardial viability in this patients population.

A. INTRACORONARY DOPPLER MEASUREMENTS AND MYOCARDIAL VIABILITY

Lepper et al. reported that CFR\textsubscript{Doppler} measured at acute stage of AMI after PCI did not represent the microvascular integrity and was not useful to predict the improvement of LV function (Lepper et al., 2000). However, there is controversy on the reliability of CFR\textsubscript{Doppler} at the earlier stage of AMI in assessing microvascular integrity and recovery of LV function. A recently published report has demonstrated that CFR immediately after primary PCI can predict LV function recovery (Bax et al., 2004). In the present study, CFR\textsubscript{Doppler} measured immediately after primary PCI, failed to correlate well with FDG-uptake of infarct-related segments. The possible cause of this may be underestimation of CFR because of increased baseline coronary flow velocity immediately after recanalization in AMI. Use of CFR to evaluate the microcirculation is limited by the fact that CFR interrogates the entire coronary system, including the epicardial artery and the microcirculation (Kern, 2000). Furthermore, because CFR represents a ratio between peak hyperemic and resting coronary flow, factors that affect resting hemodynamics, such as heart rate and contractility, may affect the reproducibility of CFR (De Bruyne et al., 1996). Previous studies have
shown that Doppler flow velocity-derived CFR is significantly reduced by tachycardia (De Bruyne et al., 1996; Rossen et al., 1993; McGinn et al., 1990) and by increased contractility (De Bruyne et al., 1996). On the other hand, hMVRI, a representative parameter for microvascular integrity, was related with myocardial viability after primary PCI in our results. The lower the hMVRI, the more the myocardium within a region of acute ischemic injury would be viable. These findings were compatible with previous observations.

One of the major findings of this study was that phasic coronary flow velocity patterns provided useful informations on myocardial viability after reperfusion. Patients with low bSAPV and short bDDT showed poorer regional FDG uptake of infarct related segments. A recently published report demonstrated that coronary flow velocity pattern was an accurate predictor of the presence or absence of complications and of in-hospital survival after AMI, and DDT higher than 600 ms was closely related with coronary microvascular injury (Yamamuro et al., 2002). Akasaka et al. reported that restricted APV with systolic reversal and rapid diastolic deceleration pattern of coronary flow was related with poor LV function improvement after stent implantation in AMI (Akasaka et al., 2000).

Based on the results of present and previous studies, for the assessment of myocardial viability using intracoronary Doppler wire immediately after primary angioplasty in AMI, phasic coronary flow velocity patterns or hMVRI could be a reliable parameter rather than CFR_{Doppler}.

B. INTRACORONARY PRESSURE MEASUREMENTS AND MYOCARDIAL
Recent studies have shown that several parameters derived from coronary pressure wire measurements were useful to assess microvascular integrity and myocardial viability. Among those previous studies, a porcine animal model study demonstrated that IMR distinguished between normal and abnormal microcirculatory function and was not significantly affected by the presence of an epicardial stenosis. Furthermore, the changes in IMR between the various epicardial and microcirculatory conditions mirrored those of true microvascular resistance, reference standard for microvascular resistance (Fearon et al., 2003). In human study, compared with CFR, IMR provided a more reproducible assessment of the microcirculation, which was independent of hemodynamic perturbations (Martin et al., 2006).

The present study demonstrated that CFR\textsubscript{thermo}, FFR and Pcw did not correlate with myocardial viability after primary PCI in AMI. Experimental study with animal model has demonstrated that CFR\textsubscript{thermo} appears to correlate better with absolute flow-derived CFR than does CFR\textsubscript{Doppler} (Fearon et al., 2003). In addition, early work validating CFR\textsubscript{Doppler} found that technical issues, such as vessel tortuosity, could limit the accuracy of this technique, presumably by not allowing the Doppler sensor to remain in the middle of the vessel (Doucette et al., 1992), and CFR\textsubscript{thermo} was expected to be more feasible than CFR\textsubscript{Doppler} in technical aspects. However, Our results revealed that CFR\textsubscript{thermo} did not overcome limitations of CFR\textsubscript{Doppler} described above, in assessing myocardial viability immediately after reperfusion in
AMI. FFR is generally applied for assessing the severity of epicardial stenosis, not for microcirculation, whereas a recent study reported that FFR is influenced by microvascular resistance (Meuwissen et al., 2001). According to another report, in patients whose target artery has suffered myocardial infarction and microvascular ischemic damage, FFR in the target vessel is higher than that in patients with normal vasodilatory capacity if the same degree of stenosis is present (Bartunek et al., 1995). Tamita et al. have demonstrated that FFR tends to be higher in patients with AMI than with angina pectoris after stent implantation in patients with the same degree of stenosis (Tamita et al., 2002). Our study demonstrated that FFR after successful PCI had a tendency to be higher in patients with non-viable myocardium and damaged microcirculation. However, FFR was not helpful to evaluate microvascular integrity and predict viability of infarct-related myocardium in AMI after primary PCI.

Pcw is related with the degree of collateral flow and has limitations to evaluate the status of microcirculation, whereas CFIb, defined as \[
\frac{Pcw - \text{central venous pressure}(Pv)}{Pcw} \]
divided by \[
\frac{Pa - Pv}{Pcw}
\], is well known to provide a simple and useful estimate of LV function improvement and clinical outcomes in AMI (Yamamoto et al., 2001). Moreover, Yamamoto et al. derived a simplified parameter that does not require the measurement of \(Pv\): \(\frac{Pcw}{Pa}\), and they have demonstrated a close inverse relation between \(\frac{Pcw}{Pa}\) and LV function improvement (Yamamoto et al., 2001). In the present study, \(\frac{Pcw}{Pa}\), adjusted Pcw with perfusion pressure (Pa), showed good correlation with myocardial viability in AMI, and this finding is compatible with a previous report mentioned above.
C. IMR AND MYOCARDIAL VIABILITY

The most important novel finding in this study is correlation between IMR and myocardial viability. IMR had significant inverse correlation with regional FDG-uptake in infarct-related segments. It has been demonstrated that current coronary physiologic parameters had limitations for evaluating the microvascular integrity or myocardial viability in earlier stage of AMI. The present study demonstrates that IMR is easily measured in humans with a commercially available pressure-temperature sensor-tipped coronary wire. It is quantitative and appears to be independent of epicardial artery disease. Because the method employs a standard coronary pressure wire, fractional flow reserve can be determined simultaneously and further help to distinguish epicardial disease from microcirculatory dysfunction. Furthermore, IMR can be reliable to assess microvascular integrity in both the acute and chronic states because IMR is derived at peak hyperemia and it would be independent of resting vascular tone and hemodynamics (Martin et al., 2006). Lastly, variations in hemodynamic status, including changes in heart rate, blood pressure, and contractility, do not significantly affect IMR measurements (Martin et al., 2006). In brief, IMR, a novel parameters for the true microvascular function is reproducible and reliable for evaluating coronary microcirculation immediately after reperfusion in AMI. Furthermore, In patients with AMI undergoing primary PCI, IMR can become a sensitive and specific parameter for the prediction of viability of damaged myocardium.
According to the result of present study, the best cut-off value for the prediction of myocardial viability was 22U.

To the best of our knowledge, this is the first report to directly compare the IMR obtained immediately after primary PCI with myocardial viability assessed by FDG-PET imaging.
V. STUDY LIMITATIONS

First, our findings are derived from a selected small population of AMI patients who were successfully treated with primary PCI. Patients with shock, hemodynamic instability or recurrent myocardial infarction were excluded from the study because the physiologic assessment is not feasible. Hence, our results may not be generalizable to all patients receiving reperfusion therapy.

Second, infarct-related coronary arteries of enrolled patients are inhomogenous. Only 68% of the culprit vessels of the study population were LAD during the study period. Physiologic assessment and clinical impact might be affected by the location of culprit arteries where the measurement was performed. Therefore, the patients had distal culprit lesions or anatomical coronary variations were excluded in this study. Further clinical trials with more homogenously selected group of patients are required to clarify the clinical value and usefulness of physiologic assessments for the prediction of myocardial viability in earlier stage of AMI after reperfusion.

Third, the effect of the severity of epicardial stenosis on measurement of microvascular resistance is controversial. Some have suggested that the minimum achievable microvascular resistance increases with the increasing severity of an epicardial artery stenosis (Sambuceti et al., 2001; Chamuleau et al., 2003). In contrast, others have reported that microvascular resistance is not affected by increasing epicardial artery stenosis if collateral flow is taken into account (Aarnoudse et al., 2004; Fearon et al., 2004). In the present study, all coronary physiological measurements were made in
arteries that were either normal or had only minor angiographic stenoses after successful stenting. In cases with severe epicardial stenosis, the simplified measurement of IMR, as used in the present study, may overestimate resistance because it does not account for collateral flow, and a more complex measurement of IMR that incorporates the coronary wedge pressure is necessary (Aarnoudse et al., 2004).

Finally, clinical follow-up was not conducted and further investigations for the clinical outcomes of the studied patients are required. In this present study, myocardial viability was assessed by FDG-PET only in short terms after reperfusion with primary PCI. The relationship between coronary physiologic parameters, LV function improvement and prognosis including major adverse cardiac events should be evaluated with further studies.
Despite the importance of the status of the microcirculation and myocardial viability in determining clinical outcomes in acute stage of MI treated with primary PCI, a reliable, on-site method for invasively assessing the state of the coronary microcirculation has been lacking. The present study clarified the phasic coronary flow velocity patterns and hMVRI indicative of severe microvascular injury as an important predictor of myocardial viability in AMI treated with primary PCI. Furthermore, IMR, a new index for specific and quantitative assessment of coronary microcirculatory resistance that can be measured in the cardiac catheterization laboratory is a useful predictor for the invasive, on-site assessment of myocardial viability in earlier stage of AMI after reperfusion.
REFERENCES


급성 심근경색증에서 일차 중재시술 후 침습적 생리학 지표들을 이용한 심근 생존능의 평가: FDG-PET와의 비교

임홍석
(지도교수: 탕승제)

배경 및 목적: 급성 심근경색증 환자에서 경색관련 심근의 미세혈관 손상 정도는 심근의 생존능에 영향을 미치며 좌심실 기능의 개선 및 환자의 예후와 밀접한 연관이 있는 것으로 잘 알려져 있으나, 이의 평가를 위한 침습적 검사법에 대한 비교 연구는 부족한 상태이다. 본 연구에서는 급성 심근경색증으로 일차 중재시술 시행 후 미세혈관 손상정도 평가와 심근의 생존능을 예측하는데 있어서 침습적 관상동맥 혈류역학 지표들의 임상적 유용성에 대해 평가하고자 한다.

대상 및 방법: 급성 심근경색증으로 진단되어 증상 발생 후 24시간 이내에 일차 중재시술을 시행 받은 19명 (남자 17명, 평균 연령 60±13세)의 환자를 대상으로 하였다. 경색관련 관상동맥에 스텐트 삽입을 이용한 성공적인 중재시술 후 도플러 철선을 삽입하여 관상동맥 혈류 예비력(Doppler coronary flow reserve, CFR_{Doppler}), 최대 충혈시 미세혈류 저항 지수(hyperemic microvascular resistance index, hMVRI)와 위상적 관상동맥 혈류 속도 형태(phasic coronary flow velocity pattern)를 측정 및 관찰하였으며, 압력 철선을 이용하여 온도희석법(thermodilution)에 의한 관상동맥 혈류 예비력(thermodilution coronary flow reserve)을 이용하여 심근의 생존능을 평가하였다.
reserve, CFRthermo), 분별 혈류 예비력 (fractional flow reserve, FFR) 및 관상동맥 채기압(coroanry wedge pressure, Pcw)을 측정하였다. 관상동맥 채기압은 평균 대동맥압 (mean aortic pressure, Pa)으로 나누어 Pcw/Pa를 구하였으며, 최대 충혈 시 원위부 관상동맥압 (distal coronary artery pressure, Pd)과 평균 혈류 동과 시간 (mean transit time, Tmn)의 곱으로 정의 되는 미세순환 저항 지수 (index of microcirculatory resistance, IMR)를 산출하였다. 심근의 생존능 평가를 위해 일차 중재시술 후 7일 이내에 13F-fluorodeoxyglucose (FDG) 양전자 방출 단층 촬영 (positron emission tomography, PET)을 시행하여 경색 관련 심근 부위의 FDG 섭취율을 계산하여 관상동맥 혈류 역학 지표들과 비교하였다.

결과 : 도플러 철선을 이용하여 측정한 지표들 중 경색관련 심근의 FDG 섭취율과 연관성이 있는 지표는 기저시 평균 최대 혈류 속도 (baseline average peak velocity, bAPV) (r=0.530, p=0.020), 최대 충혈시 평균 최대 혈류 속도 (hyperemic average peak velocity, hAPV) (r=0.675, p=0.002) 및 hMVRI (r=-0.534, p=0.018)였다. 위상적 관상동맥 혈류 속도 형태 지표들은 모두 경색 관련 심근의 FDG 섭취율과 유의한 상관관계를 나타내었다 (기저시 이완기 혈류의 감속시간, baseline deceleration time of diastolic flow velocity (DDT), r=0.533, p=0.019; 최대 충혈시 이완기 혈류의 감속시간, hyperemic DDT, r=0.513, p=0.025; 기저시 수축기 평균 최대 혈류속도, bSAPV, r=0.592, p=0.008). 압력 철선을 이용한 지표들 중 IMR 및 Pcw/Pa은 경색 심근부위의 FDG 섭취율과 유의한 역상관 관계를 보였으나 (r=-0.660, p=0.002; r=-0.601, p=0.007). CFRDoppler, CFRthermo, FFR 및 PCw는 연관성이 없었다. FDG 섭취율 50%이상을 기준으로 생존 심근을 정의 하였을 때, 심근의 생존능 예측에 대한 receiver operating characteristic (ROC) curve 분석에서 IMR이 가장 넓은 area under curve (AUC)를 나타내었으며 (0.856, 95% CI [0.620-0.970]), 기준치를 22로 하였을 때 민감도 78%, 특이도 90%와 86%의 정확도를 나타내었다.
결론: 도플러 및 압력 철선을 이용한 관상동맥 혈류 역학 지표들의 측정은 급성 심근경색증의 일차 중재술 후 생존 심근을 평가하는데 유용하며, IMR은 미세혈관 손상 정도를 정량적으로 평가할 수 있는 새로운 지표로서, 일차 중재시술 후 급성기에 심근의 생존능을 예측하는데 임상적으로 유용한 지표이다.

핵심 되는 말: 급성 심근경색증, 일차 중재시술, 관상동맥 혈류 역학 지표, 심근 생존능, 미세혈류 저항 지수 (IMR)