Qualitative and Quantitative Assessment of Perfusion

Hyun Ju Yoon
Chonnam National University Hospital
Gwangju, Korea
ISCHEMIC CASCADE

Blood flow mismatch → Diastolic dysfunction

Perfusion defects on nuclear imaging, MCE

Diastolic dysfunction → Systolic dysfunction

Wall motion abnormalities on DSE

Systolic dysfunction → ECG abnormalities

ST shift on TMT

ECG abnormalities → Symptoms

Symptoms → Angina
The occurrence of myocardial perfusion deficits is a very sensitive indicator of ischemia in the presence of significant coronary artery stenoses.
Perfusion and Mortality

Gibson, Circulation 2000
Assessment of Myocardial Perfusion

- PET Scan
- MRI
- CT scan
- Nuclear Scan
- Contrast Echo
Problems in Echo
Myocardial Perfusion Imaging

Conventional Two Dimensional Echo

- Blood in the microvasculature
  - Weak backscatter
  - Low velocity

- Bright myocardial echogenecity
Coronary Circulation
Methods to Enhance Echo from Blood in the Microvasculature

• Contrast Agents Imaging

• Technologies and Techniques
Contrast Echocardiography

Increased echogenicity by microbubbles within the cardiac chambers or vascular structure
Contrast Echocardiography

• Many benefits including:
  – Safety
  – High specificity, sensitivity, negative predictive value,
  – Good visualization despite cardiac motion
  – Echo equipment is widely available
  – Quick
  – Non-invasive
  – Radiation-free
  – Portable
  – Inexpensive
Contrast Echocardiography

- Improved EBD (Regional/Global function)
- Delineation of LV hypertrophy
- Rescue of un-interpretable studies (e.g. ICU)
- Improved stress echocardiography
- Doppler signal enhancement (AS/PV)
- Definition of structural abnormalities (Thrombus, Pseudoaneurysm)
- Myocardial perfusion
Application of Myocardial Contrast Echocardiography

• to assess risk area and infarct size
• to evaluate the presence of collaterals
• to evaluate viable myocardium after acute infarction
• to delineate reperfusion reflow zones
• to predict prognosis and functional discovery after revascularization
<table>
<thead>
<tr>
<th>Modality</th>
<th>MI</th>
<th>Real-time imaging</th>
<th>Residual myocardial tissue signals</th>
<th>Need for background subtraction</th>
<th>Endocardial border delineation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harmonic B-mode</td>
<td>0.6</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Poor</td>
</tr>
<tr>
<td>Power Doppler</td>
<td>&gt; 1.0</td>
<td>No</td>
<td>Few*</td>
<td>No</td>
<td>Good</td>
</tr>
<tr>
<td>Pulse inversion</td>
<td>0.3</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Moderate</td>
</tr>
<tr>
<td>Power pulse inversion</td>
<td>&lt; 0.15</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Good</td>
</tr>
<tr>
<td>Power modulation</td>
<td>&lt; 0.15</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Good</td>
</tr>
<tr>
<td>Coherent imaging</td>
<td>&lt; 0.15</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Good</td>
</tr>
</tbody>
</table>

MI = mechanical index; * = wall motion artifacts can be minimized with proper machine settings
About the Ideal Microbubble

- About 3 μm in diameter (Smaller than RBC)
- Contain gases of low diffusibility and solubility
- Nontoxic/easily eliminated
- Administered intravenously
- Passes easily through microcirculation
- Physically stable
- Acoustically responsive
  - Stable harmonics
  - Capable of rapid disruption
- Reliable and linear relationship
• Myocardial perfusion can be assessed with continuous infusion of microbubbles.
• When the microbubbles have reached steady-state concentrations, a high mechanical index pulse is used to destroy the bubbles in the imaging plane.
• The subsequent replenishment of microbubbles is related to myocardial perfusion.
• Areas that are hypoperfused will have a slower return of microbubbles, whereas areas that are well perfused will have a more rapid return of microbubbles.

• After the high mechanical index pulse, images can be obtained in a gated intermittent mode with high mechanical index pulses or in a real-time mode with low mechanical index pulses.
Analysis of Perfusion

• Qualitative analysis
  - For routine clinical use
  - by visual comparison of the contrast enhancement in different myocardial regions
  - looking for abnormalities in the rate or amount of contrast replenishment after a high MI pulse.
Background Subtraction

Images are achieved with low–mechanical index pulse sequence schemes designed to assess myocardial perfusion. No signals from the myocardium before contrast administration (A), but excellent LVO (B) and eventual myocardial contrast (C) after venous infusion of contrast.
Case (77/F) chest pain
Case (77/F) chest pain
Case (77/F) chest pain
An Example of a subendocardial Perfusion Defect

The defect is evident in the anteroseptal and apical segments of the left ventricle during the replenishment phase of contrast after a high-MI impulse during adenosine stress imaging.

Inducible ischemia in the post/apical and inf/apical regions that correlate to the significant stenosis of LCX and RCA in CAG.
• Quantitative
  - involves fitting parameters to the time intensity curves of microbubble replenishment.
  - The reappearance rate of microbubbles is related to myocardial blood flow velocity, and the plateau value is related to the microvascular cross-sectional area.
  - Absolute myocardial blood flow can also be determined with myocardial blood volume, which can be assessed as the ratio of the signal intensity of the myocardium to LV.
Normal Myocardial Replenishment

With real-time perfusion image, the myocardial replenishment is after a high–mechanical index (MI) impulse.

GOF is a measure of how well the function fits the measured data.
Time-to-Peak *interval from time zero to the image* where the intensity in the ROI is a maximum.

*maximum intensity in the ROI that occurs after time zero.*

Time corresponding to the image where the signal from the ROI
\( \beta \) is the rate constant of the wash in and is expressed in units of 1/seconds. 

\( \frac{1}{\beta} \) is the time required for wash in to 63% of total enhancement.

Baseline intensity: estimated intensity at time zero.

Asymptotic value: ultimate enhancement.

Amplitude of enhancement: difference between the time zero and the ultimate enhancement.
### Data Summary

<table>
<thead>
<tr>
<th>ROI</th>
<th>BI</th>
<th>A</th>
<th>$\beta$</th>
<th>GOF</th>
<th>AT</th>
<th>TTP</th>
<th>PI</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>8.42</td>
<td>7.22</td>
<td>0.88</td>
<td>0.97</td>
<td>2.86</td>
<td>5.67</td>
<td>7.75</td>
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<td>2</td>
<td>6.03</td>
<td>6.35</td>
<td>0.73</td>
<td>0.91</td>
<td>2.86</td>
<td>3.80</td>
<td>6.67</td>
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<tr>
<td>3</td>
<td>4.82</td>
<td>12.21</td>
<td>0.91</td>
<td>0.98</td>
<td>1.92</td>
<td>3.80</td>
<td>13.05</td>
</tr>
</tbody>
</table>
Parameters BI, A and β are used to minimize error between measured data and function

\[ BI + A(1 - e^{-\beta \cdot t}) \]

This curve is based on destruction-re-flow technique using a continuous infusion.

A nonlinear, least-square, curve fit using an interior trust region method is performed to quickly and accurately identify the parameters based on the data.

Log Compression vs. Antilog Data

- Antilog data more mathematically justifiable.
- Log compression reduces effect of very bright pixels in ROI.
- Log compression compresses changes seen in time intensity curve.
- Less Noisy
- More rapid approach to final value
Advantage of MCE Perfusion

- MCE has an advantage over SPECT, PET, and CT perfusion imaging because it does not involve ionizing radiation.
- Compared with SPECT, MCE has improved spatial resolution, detection of subendocardial ischemia.
- MCE also has the ability to perform absolute quantification of myocardial blood flow.
- Imaging can be performed during pharmacological stress with inotropes or vasodilators or with exercise.
Limitation of MCE Perfusion

- Suboptimal images as the result of respiratory motion, body habitus, or lung disease.
- Attenuation from the microbubbles may result in artifacts in the basal segments of LV. It can limit image quality and adequate spatial coverage of the ventricle, resulting in increased variability and decreased reproducibility.
- Operator-dependent factors such as maintaining a constant image plane during replenishment of microbubbles.
Thank you very much!