Assessment of Myocardial Perfusion using a 3 Tesla Cardiac Magnetic Resonance

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Sequence of Myocardial Events in the Progression of Ischemia

- Subendocardial perfusion deficit
- Transmural perfusion deficit
- Diastolic dysfunction
- Systolic dysfunction
- ECG change
- Angina

Ischemia

Time
Myocardial Perfusion Reserve

Resting myocardial blood flow is normal until 85% stenosis. Max myocardial blood flow begins to decline from 45% stenosis.

Gould KL et al., Am J Cardiol 1974; 34:48-55
Modalities of Imaging
Myocardial Perfusion

- SPECT: $\text{Tl}^{201}$
- PET: $\text{N}^{12}\text{H}_3$
- Contrast Echo
- MDCT
- MRI: first pass contrast enhancement
Purpose

- To test the feasibility of the first-pass contrast-enhanced perfusion technique on 3 Tesla MR system
- To establish the normative perfusion indices in normal subjects
- To determine the accuracy of 3T CMR in detecting significant coronary artery stenosis
Subjects and Methods

- **Study population**
  - 12 patients with angina pectoris, hospitalized for coronary angiography within 72 hours after CMR (8 male; age, 56.3±15.2 years)
  - 30 age-matched volunteers without history of cardiac disease (17 male; age, 48.8±5.0 years)

- **MR scanning protocol**
  - 3 Tesla MR Scanner (Trio, Siemens)
  - Saturation recovery TurboFLASH pulse sequence
    - TR/TE/flip angle = 160 ms/0.98ms/10°, slice thickness = 8mm,
    - FOV=300×400 mm, matrix size=144×192, in-plane resolution=2.08 mm
  - 3 short-axis slices at basal, mid and apical levels
  - Gd-DTPA (0.05mmole/kg) bolus injected @ 4 ml/sec
  - Hyperemia induced by dipyridamole 0.14mg/kg/min for 4 min
  - Scanning at 7th min for 80 cardiac cycles
  - Antidote aminophylline 125mg after stress test
Multislice SR-prep TurboFLASH for Perfusion Study

Time point 1 . . . . . . Time point 80
Myocardial Perfusion Imaging
Definition of coronary artery territories

Regional segmentation to coronary arterial territories

Cerqueira MD et al. Standardized myocardial segmentation and nomenclature for tomographic imaging of the heart. Circulation 2002;105:539-542
Myocardial Segmentation

The short axial view of LV wall myocardium and LV cavity were selected by user-traced endo- and epicardial contours, six segmental points were identified.

The LV wall was subdivided into six transmural myocardial segments.
Signal Time Curves

1) SI curve for LV cavity and myocardium were plotted from 80 images for each slice position
2) Baseline and first-pass portion were identified from AIF signal time curve
Post-processing of SI curves

Normalized and Truncate Signals

Normalized Signal to arbitrary unit (A.U.) by:

\[
\frac{S_i}{S_{\text{sector mean}}} \times S_{\text{total mean}} = S_{i,\text{normalized}}
\]

Correct for depth dependency

\[
S_{i,\text{base}} = \text{mean} \left[ S_{i,\text{normalized}} \right]_{\text{base-end}} - \left[ S_{i,\text{normalized}} \right]_{\text{base-start}}
\]

Subtract baseline signal

\[
S_{i,\text{normalized}} - S_{i,\text{base}} = SI(A.U.)
\]

Transform heartbeat to actual time scale and truncate signal from foot to heel

Time window
Curve Fitting

Curve Fitting by using Gamma Variate Function

\[ gvf(a, b, c, t) = a(t^b)e^{\frac{-t}{c}} \]

*Thompson HK, Circ Res 1964;14:502-515*
Perfusion indices

**Upslope**: Maximum upslope of the SI curve normalized by Upslope of LVC
**Peak value**: Peak value of SI normalized by PV of LVC
**tPeak**: Time period from contrast arrival to the peak
**AUC**: Area under the SI curve from the foot to peak normalized by tPeak
The vasodilatation responses after dipyridamole infusion were tested by Wilcoxon matched pairs test.

Group differences in reserve indices were tested by Kruskal-Wallis ANOVA test and used Dunn’s multiple comparison $t$-test to compare all pairs of groups. Significance was defined as $P<0.05$.

Receiver operating characteristic (ROC) analyses were performed to evaluate the diagnostic sensitivity, specificity, and accuracy for each index.
Results

• MRI was successfully performed in all subjects.
• Most participants showed significant homodynamic change between rest and dipyridamole infusion.
• Two control subjects showed minimal difference in HR, known as vasodilatation non-responders, and were not included in the study.
• coronary angiography showed 6/12 patients had significant coronary artery stenosis in 10 vessels: 4 in LAD, 3 in RCA and 3 in LCX.
## Results

### Hemodynamics

<table>
<thead>
<tr>
<th></th>
<th>Rest</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heart Rate (bpm)</td>
<td>68±7</td>
<td>90±10*</td>
</tr>
<tr>
<td>Systolic blood pressure (mmHg)</td>
<td>119±16</td>
<td>113±17</td>
</tr>
<tr>
<td>Diastolic blood pressure (mmHg)</td>
<td>74±11</td>
<td>71±10</td>
</tr>
<tr>
<td>Pulse pressure product (mmHg*bpm)</td>
<td>8082±1551</td>
<td>10232±2099*</td>
</tr>
</tbody>
</table>

Values are mean±SD.

*Significant differences between rest and stress (p<0.05).*
Results

Normative perfusion indices (N = 30)

<table>
<thead>
<tr>
<th></th>
<th>LAD</th>
<th>RCA</th>
<th>LCX</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upslope</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rest</td>
<td>0.10±0.03</td>
<td>0.09±0.02</td>
<td>0.09±0.03</td>
</tr>
<tr>
<td>stress</td>
<td>0.16±0.06</td>
<td>0.14±0.04</td>
<td>0.16±0.06</td>
</tr>
<tr>
<td>ratio</td>
<td>1.62±0.40</td>
<td>1.69±0.39</td>
<td>1.76±0.50</td>
</tr>
<tr>
<td><strong>PV</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rest</td>
<td>0.20±0.05</td>
<td>0.18±0.04</td>
<td>0.18±0.04</td>
</tr>
<tr>
<td>stress</td>
<td>0.26±0.06</td>
<td>0.25±0.05</td>
<td>0.27±0.07</td>
</tr>
<tr>
<td>ratio</td>
<td>1.36±0.28</td>
<td>1.39±0.28</td>
<td>1.50±0.34</td>
</tr>
<tr>
<td><strong>tPeak</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rest</td>
<td>16.46±4.16</td>
<td>17.73±4.56</td>
<td>17.08±4.58</td>
</tr>
<tr>
<td>stress</td>
<td>10.77±2.04</td>
<td>11.34±2.25</td>
<td>11.10±2.56</td>
</tr>
<tr>
<td>ratio</td>
<td>0.68±0.18</td>
<td>0.68±0.17</td>
<td>0.68±0.18</td>
</tr>
<tr>
<td><strong>AUC</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>rest</td>
<td>7.39±2.73</td>
<td>6.57±2.48</td>
<td>7.19±2.86</td>
</tr>
<tr>
<td>stress</td>
<td>10.03±3.56</td>
<td>10.03±4.39</td>
<td>10.96±5.11</td>
</tr>
<tr>
<td>ratio</td>
<td>1.53±0.48</td>
<td>1.81±1.01</td>
<td>1.67±0.50</td>
</tr>
</tbody>
</table>
Results

Normal subject

LAD stenosis
Results

Upslope & Upslope ratio (widely used to indicate MPR)
Results

PV & PV ratio
Results

tPeak & tPeak ratio
Results

AUC & AUC ratio

[Charts showing AUC and AUC ratio with p-values]
## Results

**Receiver Operating Characteristic (ROC) results**

<table>
<thead>
<tr>
<th></th>
<th>Upslope</th>
<th>PV</th>
<th>tPeak</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cutoff value</strong></td>
<td>1.20</td>
<td>1.20</td>
<td>0.79</td>
<td>1.15</td>
</tr>
<tr>
<td><strong>Sensitivity</strong></td>
<td>92%</td>
<td>85%</td>
<td>81%</td>
<td>81%</td>
</tr>
<tr>
<td><strong>Specificity</strong></td>
<td>85%</td>
<td>90%</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td><strong>Accuracy area</strong></td>
<td>88%</td>
<td>88%</td>
<td>84%</td>
<td>79%</td>
</tr>
</tbody>
</table>
Discussions

• Upslope ratio using 1.5T

<table>
<thead>
<tr>
<th>sensitivity</th>
<th>specificity</th>
<th>accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>90%</td>
<td>83%</td>
<td>87%</td>
</tr>
<tr>
<td>88%</td>
<td>90%</td>
<td>89%</td>
</tr>
<tr>
<td>92%</td>
<td>85%</td>
<td>88%</td>
</tr>
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(Al-Saadi et al.)
(Nagel et al.)
(NTUH 3T CMR)

• SPECT or PET:

<table>
<thead>
<tr>
<th>sensitivity</th>
<th>specificity</th>
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<tbody>
<tr>
<td>83%~95%</td>
<td>53%~95%</td>
</tr>
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</table>

(Demer et al.; Go et al.; Schwaiger et al.; Muzik et al.)
## Discussions

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<th>specificity</th>
<th>accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upslope ratio in 3T CMR</strong></td>
<td>92%</td>
<td>85%</td>
<td>88%</td>
</tr>
<tr>
<td><strong>PV ratio in 3T CMR</strong></td>
<td>85%</td>
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<td><strong>AUC ratio in 3T CMR</strong></td>
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<td>79%</td>
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Conclusions

• We have validated clinical feasibility of first-pass contrast-enhanced myocardial perfusion technique on a 3T MR system.
• The normative values of perfusion indices and their corresponding stress to rest ratios can serve as reference values.
• The diagnostic power for ischemic heart disease with 3T is at least comparable to the reported values obtained from 1.5T systems.
Potential Application with 3T CMR

Ischemia

- Subendocardial perfusion deficit
- Transmural perfusion deficit
- Diastolic dysfunction
- Systolic dysfunction
- ECG change
- Angina

Time

Requires high spatial resolution and SNR
Thanks for your attention