Value of Quantitative Analysis of Myocardial Perfusion MRI and CT

Hajime Sakuma, MD, PhD
Professor and Chairman, Department of Radiology
Mie University School of Medicine
Vice Dean, Mie University Graduate School of Medicine
Tsu, Mie, Japan

I have noting to disclose.
Stress myocardial perfusion MRI

- Increasingly used to evaluate myocardial ischemia.
- Visual assessment in most institutions.

40-year-old man, chest pain on effort
Stress-induced ischemia in LAD territory

Mie University Hospital
Cardiovascular magnetic resonance and single-photon emission computed tomography for diagnosis of coronary heart disease (CE-MARC): a prospective trial


4065 patients assessed for eligibility
3313 excluded
1922 ineligible
683 withdrawal consent
338 division decision
73 other
752 randomly assigned

378 assigned to CMR then SPECT

349 underwent CMR
29 CMR not done

333 underwent SPECT
46 SPECT not done

365 underwent angiography
12 angiography not done

676 CMR and angiography assessable
50 CMR unavailable
10 angiography unavailable
628 CMR and angiography assessable
676 SPECT and angiography assessable
50 SPECT unavailable
8 angiography unavailable
18 SPECT and angiography unavailable

A All patients (angiographic cutoff ≥50% LMS; ≥70% for LAD, LCX, and RCA)

Sensitivity
CMR 0.89 (0.86–0.91)
SPECT 0.74 (0.70–0.78)
p < 0.0001
Prognostic Value of CMR and SPECT (CE-MARK)

Quantification of myocardial blood flow (MBF)
64-year-old woman, Diabetes, LAD stenosis

Rest (ml/min/100g)

Stress


Mie University Hospital
Potential benefits of perfusion MR quantification in patients with CAD

• Objective detection of myocardial ischemia.

• Quantification of treatment response.

• Improved evaluation of microvascular disease
Quantitative analysis of perfusion MRI

- **Arterial input function (AIF):**
  Time-signal intensity (SI) curve in the LV blood pool.

- **Myocardial output function:**
  Time-SI curve in myocardial segments.
Key points for quantitative assessment of MBF from perfusion MRI

- Correction for saturation of blood input signal
- Selection of mathematical model
- Correction for extraction fraction of gadolinium contrast medium
Correction for blood saturation with a dual-bolus method

Blood phantom study

Observed blood signal

Line by extrapolation

Peak concentration 0.05 mmol/kg

Peak concentration 0.1 mmol/kg

Blood saturation correction with dual bolus approach

Mathematical models in recent literatures

<table>
<thead>
<tr>
<th>Model</th>
<th>MID</th>
<th>Fermi</th>
<th>DP</th>
<th>ETM</th>
<th>Tofts</th>
<th>Patlak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pack NA&lt;sup&gt;1&lt;/sup&gt;</td>
<td>〇</td>
<td>〇</td>
<td>〇</td>
<td></td>
<td></td>
<td>〇</td>
</tr>
<tr>
<td>Biglands JD&lt;sup&gt;2&lt;/sup&gt;</td>
<td>〇</td>
<td>〇</td>
<td></td>
<td>〇</td>
<td></td>
<td>〇</td>
</tr>
<tr>
<td>Handayani A&lt;sup&gt;3&lt;/sup&gt;</td>
<td></td>
<td>〇</td>
<td>〇</td>
<td>〇</td>
<td></td>
<td>〇</td>
</tr>
</tbody>
</table>

- **Linear, shift-invariant model (Deconvolution)**
- **Tracer kinetic model**
  - 2 compartment
  - 1 compartment
  - Complex → Simple

**Definitions**
- MID: model-independent deconvolution
- DP: distributed-parameter
- ETM: extended Tofts model

*References*
- 1. MRM2010
- 2. Radiology 2015
- 3. Invest Radiol 2015
Patlak model (Uptake model)

Linear correlation is no longer maintained when back-diffusion from EES become significant.

\[ K_{\text{trans}} = \text{slope of least square fitted line} \]

\[ \int_0^t \dot{C}_p(\tau) \, d\tau \]

$K_{\text{trans}} = \text{[Myocardial Blood flow]} \times \text{[Extraction fraction]}$
MBF and extraction fraction of Gd-DTPA

\[ E = 1 - \exp\left(-\frac{0.14 \times \text{MBF} + 0.56}{\text{MBF}}\right) \]

65-year-old man, chest pain on effort

\[ ^{15} \text{O-H}_2\text{O PET/CT} \]

Stress MBF

Rest MBF

MPR

Coronary angiography

Mie University Hospital
65-year-old man, LCX#14 99%

Stress

Rest

MPR

Fermi DC

$^{15}$O-H$_2$O PET/CT

LGE

Mie University Hospital
Correlation of vessel-based MBF between $^{15}$O-water PET and perfusion MRI

\[ y = 1.1234x \]

\[ R = 0.82, \ p<0.0001 \]
**Prediction of reduced Doppler CFR of \( \leq 2 \) with quantitative perfusion MRI (MPR \( \leq 2 \))**

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensitivity (%)</td>
<td>87.5% [61.7-98.5]</td>
</tr>
<tr>
<td>Specificity (%)</td>
<td>90.0% [68.3-98.8]</td>
</tr>
<tr>
<td>Positive Predictive Value (%)</td>
<td>87.5% [61.7-98.5]</td>
</tr>
<tr>
<td>Negative Predictive Value (%)</td>
<td>90.0% [68.3-98.8]</td>
</tr>
</tbody>
</table>

Stress myocardial perfusion imaging at Mie University Hospital
Comprehensive cardiac CT study

Entry 0

Topogram Calcium scoring
Vasodilator stress
NTG

Leaving 30(min)

Pre-contrast CT
Dynamic CTP
Coronary CTA

CT delayed enhancement

Pre-contrast
Stress perfusion
Coronary stenosis
Infarct/fibrosis

Mie University Hospital
CT myocardial perfusion imaging

**Static stress perfusion**
- Coronary CTA at estimated optimal time frame during pharmacologic vasodilation.
- Qualitative / semi-quantitative assessment

**Dynamic stress perfusion**
- Repeated low-dose scans during contrast wash-in/out.
- Quantitative assessment
  Myocardial blood flow (MBF) calculated from time-attenuation curves
Dynamic Stress CTP

Quantitative Analysis

$$MBF = \frac{\text{max slop (tissue TAC)}}{\text{maxmum AIF}}$$

5 minutes to obtain voxel-based MBF map on console
69-year-old woman, Effort angina

Agatston Score: RCA 1438, LAD 621

Mie University Hospital
Stress dynamic CT perfusion

69-year-old female, Effort angina
69-year-old woman, Effort angina
69-year-old woman, Effort angina

Successful PCI/ROTA+DES to RCA#2 90%→0%
69-year-old woman, Follow up CT

Pre PCI

Post PCI

Mie University Hospital
## Diagnostic accuracy of stress CTP at vessel level

Reference standard: FFR

<table>
<thead>
<tr>
<th>Author</th>
<th>n</th>
<th>Analysis</th>
<th>Sensitivity</th>
<th>Specificity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ko (2012)</td>
<td>103</td>
<td>Static, TPR</td>
<td>74</td>
<td>66</td>
</tr>
<tr>
<td>Ko (2013)</td>
<td>86</td>
<td>Static, wall thickness</td>
<td>76</td>
<td>84</td>
</tr>
<tr>
<td>Bittencourt (2013)</td>
<td>303</td>
<td>Static, visual</td>
<td>55</td>
<td>95</td>
</tr>
<tr>
<td>Choo (2013)</td>
<td>81</td>
<td>Static, visual</td>
<td>93</td>
<td>90</td>
</tr>
<tr>
<td>Yang (2015)</td>
<td>210</td>
<td>Static, visual</td>
<td>80</td>
<td>95</td>
</tr>
<tr>
<td>Greif (2013)</td>
<td>195</td>
<td>Dynamic, MBF</td>
<td>95</td>
<td>74</td>
</tr>
<tr>
<td>Huber (2013)</td>
<td>96</td>
<td>Dynamic, Upslope</td>
<td>83</td>
<td>88</td>
</tr>
<tr>
<td>Rossi (2014)</td>
<td>210</td>
<td>Dynamic, MBF</td>
<td>88</td>
<td>90</td>
</tr>
<tr>
<td>Kono (2014)</td>
<td>91</td>
<td>Dynamic, MBFratio</td>
<td>98</td>
<td>70</td>
</tr>
</tbody>
</table>
MBF (ml/min/g) quantified by dual-source stress CTP in patients with suspected CAD

<table>
<thead>
<tr>
<th>Author</th>
<th>Remote normal</th>
<th>Stenotic</th>
<th>The best cutoff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ho (2010)</td>
<td>1.21 ± 0.31</td>
<td>0.65 ± 0.21</td>
<td>-</td>
</tr>
<tr>
<td>Bamberg (2011)</td>
<td>1.05 ± 0.34</td>
<td>0.73 ± 0.26</td>
<td>0.75</td>
</tr>
<tr>
<td>Rossi (2013)</td>
<td>1.09</td>
<td>0.62</td>
<td>0.78</td>
</tr>
<tr>
<td>Greif (2013)</td>
<td>1.23 ± 0.34</td>
<td>0.79 ± 0.26</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Low MBF can be explained by lack of correction for extraction fraction.

\[ K_{\text{trans}} = [\text{Myocardial Blood flow}] \times [\text{Extraction fraction}] \]
Advantages of perfusion CT quantification in patients with CAD

- Objective detection of myocardial ischemia.
- Less sensitive to artifacts.
- Quantification of treatment response.
- Improved evaluation of microvascular disease
Acknowledgements

Kakuya Kitagawa (CT)  Masaki Ishida (CMR)  Yasutaka Ichikawa  Yasutaka Goto

Radiology

Makiko Kubooka  Yusuke Kurobe  Syoshe Kusita

Radiology

Naoki Nagasawa  Akio Yamazaki  Shinichi Takase, Tsunehiko Yamahata

Technologists