MR Imaging of Atherosclerosis

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Biomarkers in Atherosclerosis
Adapted from Choudhury et al. Nat Rev Drug Discov. 2004

Vulnerable Plaque: Pathologists View

Signal Quantification
Pulse sequences can be designed to allow quantification of tissue T1, T2 and T2* relaxation times.
T1 and T2* mapping allows quantification of contrast agents based on their T1 and T2* values.

T1 Mapping: Saturation Recovery

1/T1 = 1/T10 + r1 * [Gd]

Quantification of Contrast Uptake

<table>
<thead>
<tr>
<th>subject</th>
<th>#1</th>
<th>#2</th>
<th>#3</th>
<th>#4</th>
<th>mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1pre[ms]</td>
<td>737</td>
<td>737</td>
<td>737</td>
<td>737</td>
<td>n/a</td>
</tr>
<tr>
<td>T1post[ms]</td>
<td>366</td>
<td>377</td>
<td>354</td>
<td>316</td>
<td>353 ± 27</td>
</tr>
<tr>
<td>c [µM]</td>
<td>92</td>
<td>86</td>
<td>98</td>
<td>121</td>
<td>99 ± 15</td>
</tr>
</tbody>
</table>
T1 Mapping: Inversion Recovery

\[ \frac{1}{T_1} = \frac{1}{T_{10}} + r_1 \cdot [\text{Gd}] \]

Estimation of Relaxivity

\[ R_1 = R_{10} + r_1 \cdot [\text{Gd}] \]

Quantification of Contrast Uptake

\[ \text{signal} = A \cdot e^{-n \cdot T_E / T_{2*}} \]

T2* Quantification

\[ R_2^* = R_{20}^* + r_2^* \cdot [\text{Gd}] \]

Average T2* Thrombus Value [ms]

Days after Venous Thrombosis

\[ y = 7.3238 \ln(x) + 10.314 \]

\[ R^2 = 0.94163 \]

Thrombus Average R2* value [Hz]

\[ y = 3.1234x - 97.831 \]

\[ R^2 = 0.96109 \]
Tissue Characterization

Pulse sequences can be designed to allow
differentiate between tissues based on their T1 and T2
relaxation times

T1w, T2w and PDw MRI
allows enhancing or
suppressing tissues based
on their T1, T2 or proton
density values

BLACK BLOOD T1W IMAGING

Trigger Delay

ECG

Mid-diastole

Dual-IR, QIR

3D TSE or TFE

TE = shortest

FatSat

Dual-IR Black Blood Imaging

ECG triggered: TR = every heart beat
Non triggered: every TR= 300-500ms

DUAL-INVERSION T1W IMAGING

Trigger Delay

ECG

Mid-diastole

3D TSE

TE = shortest

FatSat

ECG triggered: TR = every heart beat
Non triggered: every TR= 300-500ms

QUADRUPLE INVERSION

Trigger Delay

ECG

Mid-diastole

TI1

TI2

3D TSE

TE = shortest

FatSat

ECG triggered: TR = every heart beat
Non triggered: every TR= 300-500ms

QIR Black Blood Imaging

Post contrast: fibrous cap enhancement
iMSDE Based Black Blood Imaging

\[ \Phi(t) = \gamma \cdot r_0 \cdot G \cdot t \]

\[ \Phi(v, t) = \gamma \cdot v \cdot G \cdot t^2 \]

**Static spins:**

**Moving spins:**

Comparison– Dual-IR vs. iMSDE

Imaging Sciences
Interdisciplinary Medical Imaging Group

T2W IMAGING

ECG

Trigger Delay

Mid-diastole

Dual-IR

QIR

FAT SAT

Dual-IR + NAV

Pre-pulse

Imaging

ECG triggered: TR = every 2nd heart beat
Non triggered: every TR= 2000-3000ms

PDW IMAGING

ECG

Trigger Delay

Mid-diastole

Dual-IR

QIR

FAT SAT

Dual-IR + NAV

Pre-pulse

Imaging

ECG triggered: TR = every 2nd heart beat
Non triggered: every TR= 2000-3000ms

Contrast Enhanced Imaging

Pulse sequences can be designed to visualize contrast agents based on their T1 or T2 shortening effects

Inversion recovery or DCE-MRI

allows enhancing tissues with gadolinium uptake while suppressing tissues without contrast uptake based on their T1 relaxation time values
**INVERSION RECOVERY (T1W)**

- Trigger Delay
- ECG
- IR
- NA
- FSE
- 3D TFE

**Inversion Recovery Imaging (T1w)**

- ECG
- Mid-diastole
- Inversion delay
- trigger delay
- Gd
- background tissue blood

**Intraplaque Hemorrhage Imaging**

Kawasaki T et al. JACC Imaging. 2009

**DCE-MRI**

Kawasaki T et al. JACC Imaging. 2009

**DCE-MRI Images**

\[ \text{SI}(t) = \text{C}_p(t) - \text{C}_p(t+\Delta t) + \int_0^{\Delta t} \text{C}_p(t+\Delta t) \, dt \]

- \( \text{C}_p(t) \): tissue Gd concentration
- \( \text{C}_p(t+\Delta t) \): plasma Gd concentration

**Non Contrast Angiography**

Spin Labeling or T2prep
allows enhancing or suppressing tissues based on their T1, T2 values
Contrast Enhancement

<table>
<thead>
<tr>
<th></th>
<th>T1 [ms]</th>
<th>T2 [ms]</th>
<th>f棹 [Hz]</th>
<th>flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood</td>
<td>1200</td>
<td>250</td>
<td>0</td>
<td>yes</td>
</tr>
<tr>
<td>Muscle</td>
<td>850</td>
<td>50</td>
<td>0</td>
<td>no</td>
</tr>
<tr>
<td>Fat</td>
<td>250</td>
<td>100</td>
<td>220</td>
<td>no</td>
</tr>
</tbody>
</table>


T2 Prepulse

Contrast Enhancement
Water/Fat Coronary Imaging

Respiratory Motion Correction

Motion Correction

2D Self-Navigation
Coronary Lumen Sequence

Coronary Wall Sequence

VESSEL WALL MRI

Coronary Vessel Wall Imaging

Double Inversion Radial Sequence

iT2prep Vessel Wall Imaging (T2prep on / off)

 Courtesy: Marcelo Andia MD MSc and Markus Henningsen MSc

Li D et al. Radiology. 1996
Botnar RM et al. Circulation. 1999
Stuber M et al. JACC. 1999

Coronary Wall Sequence

3D Spiral

Trigger Delay

Mid-diastole

ECG

Local Inversion (black blood)

Conclusions

- MRI provides many contrast weightings that allow imaging
- vessel lumen
- vessel wall (morphology)
- vessel wall vascularity (DCE-MRI)
- vessel wall biology (CE-MRI)
- advanced motion correction → coronary lumen and vessel imaging