Motion Related Contrast in MRI

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Motion Encoding

**Modify** $M_z$
- Time of Flight MRA
- Arterial Spin Labeling
- Myocardial Tagging

**Modify** $M_{xy}$
- Phase Contrast MRA
- Elastography
- Diffusion Imaging

Excitation
$M_z \rightarrow M_{xy}$

Data Acquisition
Encoding $M_{XY}$ for Motion: Phase Contrast

Phase from Motion:

$\phi(t) = \int \gamma B(t) dt$

$= \int \gamma \tilde{G}(t) \cdot \tilde{r}(t) dt$

$= \int \gamma \tilde{G}(t)(\tilde{r}_0 + \tilde{V}t + ...) dt$

$= \tilde{r}_0 \cdot \int \gamma \tilde{G}(t) dt + \tilde{V} \cdot \int \gamma \tilde{G}(t) t dt + ...$

**Zeroth Moment** ($m_0$)

$k$

**First (flow) Moment** ($m_1$)

$= (\sqrt{2} + 1):1$

Bipolar Gradient:

$G$

$\delta$

$\Delta$

$m_1 = \gamma G \delta \Delta$

**How Big can $m_1$ be?**

For: $G=4G/cm$

$\delta=\Delta=50\text{ms}$

- $\pi$ per $6\mu m$
- $\text{VENC=velocity for } \phi=\pi$
- $=6\mu m/50\text{ms}=0.12\text{mm/s}$
Phase Contrast MRA

- One image with velocity encoding positive
- One image with velocity encoding negative
- Vector sum of gradients determines direction of encoding
- Display phase difference between images
- Phase difference subtracts out off-resonance and other phase effects
Phase Contrast MRA

• Phase is proportional to velocity
• Quantitate velocity from phase images and/or:
• Construct angiograms by MIP of velocity maps

MR Elastography


Taouli et al, AJR 2009; 193:14–27

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Diffusion Imaging

**Diffusion**
- Random walk
- No net displacement -> No net phase shift
- RMS displacement in time $dt \propto \sqrt{Ddt}$
- Convolution with Gaussian in image space
- Multiplication by Gaussian in K-space

In 100ms:
- Diffusion @ $10^{-3}$mm$^2$/s
  - $\sim 15\mu$m
- Flow @ 1mm/s $\sim 100\mu$m

Image Space $\xrightarrow{FT} K$-space

$$\mathcal{F}\left[e^{-\frac{x^2}{2D}}\right] = e^{-\frac{k^2D}{2}}$$

Total Attenuation:
$$\frac{S}{S_0} = e^{-D\int k^2 dt} = e^{-bD}$$

where:
$$b \equiv \int k^2 dt$$

Pulse Sequence
- RF
- G
- EPI
Time of Flight MRA

- Spoiled gradient echo with high flip angle and short TR
- Static magnetization becomes highly saturated
- Relaxed inflowing blood has much higher signal

\[
M_z(tr) = M_0 \left(1 - (1 - M_z(tr - 1)\cos(\alpha))e^{-TR/T_1}\right)
\]

\[
Signal(tr) = M_z(tr)\sin(\alpha)
\]

TR=20ms  
\[T_1=1600\text{ms}\]

\[\alpha=40^\circ\]

\[\alpha=5^\circ\]
Arterial Spin Labeling

RF
- Using RF pulses, modify (label) the longitudinal magnetization of arterial blood water, typically by inversion.
- Decay constant is $T_1$ (~1.5s)

- Wait for labeled blood to flow to target tissue
- Measure labeled magnetization in target tissue
- Delivery time is ~1s
Properties of ASL

Advantages:
• Short lived $\text{H}_2\text{O}$ tracer
  • Fast exchange into tissues
  • Kinetics related only to delivery – No outflow
  • Inherently proportional to perfusion
• Non-Invasive
  • Repeatable indefinitely

Disadvantages:
• Short lived $\text{H}_2\text{O}$ tracer
  • Strong tradeoff between delivery and $T_1$ decay
• Low SNR
  • Perfusion is $\sim 0.01\text{s}^{-1}$
The ASL Measurement

Tag by Magnetic Inversion

Control

Acquire image of tissue + relaxed blood

Acquire image of tissue + tagged blood

ASL Signal = Control - Tag $\propto$ Perfusion
Classes of ASL Labeling Methods

Continuous ASL

Pulsed ASL

Velocity Selective ASL
CASL: Flow Driven Adiabatic Inversion

Effective field in frame that rotates at $\omega_L$:

$$\vec{B}_e = B_1 \hat{i} + z(t)G_z \hat{k}$$
**PASL: Pulsed Adiabatic Inversion**

Effective field in frame that rotates with pulse:

\[
\vec{B}_e = B_1 \hat{i} + \frac{\Delta \omega}{\gamma} \hat{k}
\]
Calculation of CBF

\[ \Delta M_Z = (CBF) 2M_{0B} \int_{PLD}^{PLD+LT} e^{-t/T_1} dt \]
Clinical ASL

Ischemic Penumbra: Perfusion > Diffusion Mismatch

LICA Occlusion: Tissue at Risk

Glioblastoma Multiforme

Hyperperfusion post anoxia

Wake Forest: Deibler et al, AJNR August 2008
# Cardiac MRI - Goals

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Main Challenge: **MOTION**
- Beating
- Respiration
- Patient
Gating

Prospective

Retrospective

http://youtu.be/BhMFhbcp2Jg
Coronary Arteries
Gating/Navigation

• Cardiac Gating
• Respiratory Gating
• Breath hold
• Navigation
• Data filtering

Gated, no nav + diaphragm nav + fat nav
Myocardial Tagging

http://www.med-ed.virginia.edu/courses/rad/cardiacmr/Techniques/Tagging.html
Arterial Spin Labeling

1. Tag Arterial Blood by magnetic inversion
2. Wait for delivery of tagged blood (1-2s)
3. Image myocardium + tagged blood

Tag Image

ASL Image of tagged blood

Control Image

Image myocardium
ASL Tagging Schemes

- Pulsed Slab Tag Along Aorta
- Pulsed Slab Tag Across Aorta
- Pseudo-continuous Tag Plane
- Imaging Volume
- Pulsed 2D Tag Along Aorta
- Pulsed 2D Tag Across Aorta
2D Pulsed Tagging
Magnetization Transfer

Spin Exchange or Chemical Exchange

MT Ratio

Image Credit: http://commons.wikimedia.org/wiki/File:Conformational_states_of_PPDK.png
Magnetization Transfer: Applications

Static tissue suppression for MRA

Lesion detection in MS

CEST:
Chemical Exchange Saturation Transfer
doi:10.1038/nm.2615
Summary

ASL: 10cm, $T_1$

MRA: TOF 1cm, $T_1$; PC 1mm, $T_2$

Tagging: 1cm, $T_1$

MT: 1$\eta$m, $T_1$

Diffusion: 10$\mu$m, $T_2$