Motion Related Contrast in MRI

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Types of Motion in the Body

Gross

Diffusion

Cardiac

Exchange

Blood Flow

Perfusion

http://www.youtube.com/watch?v=wu01vlf4ORM

MR Tools for Encoding Motion

Cinematography

Time of Flight

\( M_z, T_1 \)

Phase Contrast

\( M_{xy}, T_2 \)

Indirect

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

Relaxed Blood Magnetization
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

The ASL Measurement

$\text{ASL Signal} = \text{Control} - \text{Tag} \propto \text{Perfusion}$

Classes of ASL Labeling Methods

Continuous ASL
Pulsed ASL
Velocity Selective ASL

ASL Labeling

Continuous/Pseudocontinuous
- Tagging based purely on velocity
- Tag has no spatial selectivity
- Transit delay eliminated
Calculation of CBF

\[ \Delta M_Z = (CBF) \cdot 2M_{0B} e^{\frac{-t}{T_{PLD}} + \int_{LT}^{PLD} e^{\frac{-t}{T_{PLD}}} dt} \]

Clinical ASL

Ischemic Penumbra: Perfusion > Diffusion Mismatch
Glioblastoma Multiforme
LICA Occlusion: Tissue at Risk
Hyperperfusion post anoxia

Wake Forest: Dehbler 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

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**Coronary Arteries**

![Coronary Arteries Image]

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**Gating/Navigation**

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

Gated, no nav  +diaphragm nav  +fat nav

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**Myocardial Tagging**

![Myocardial Tagging Image]

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**Coronary Arteries**

- Right coronary artery
- Left coronary artery

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**Myocardial Tagging**


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**Coronary Arteries**

- Myocardial Tagging
  - Heart 
  doi:10.1160/HC03ME.000000-09ME
Arterial Spin Labeling

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

ASL Tagging Schemes

2D Pulsed Tagging

Break
Plug for BE278: MRI Lab

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MR Tools for Encoding Motion

Cinematography

Time of Flight
($M_Z, T_1$)

Phase Contrast
($M_{XY}, T_2$)

Indirect

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

Phase from Motion:

$$\omega = \gamma B$$

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

$$= \int \gamma G(t) \dot{f}(t) dt$$

$$= \int \gamma G(t)(\ddot{f}_0 + \ddot{V} t + \ldots) dt$$

$$= \ddot{f}_0 \int \gamma G(t) dt + \ddot{V} \int \gamma G(t) t dt + \ldots$$

Bipolar Gradient:

$$m_1 = \gamma G \delta \Delta$$

How Big can $m_1$ be?

For:

$$G = 4G/cm$$

$$\delta = \Delta = 50ms$$

- $\pi$ per 6µm
- VENC=velocity for $\phi = \pi$

$$= 6\mu m/50ms = 0.12mm/s$$

Phase Contrast MRA

- Phase proportional to velocity
- Quantify velocity from phase images

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

MR Elastography


MR Tools for Encoding Motion

Cinematography

Time of Flight
\((M_z, T_1)\)

Phase Contrast
\((M_{XY}, T_2)\)

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:

Flow @1mm/s ~100um

Pulse Sequence

Image Space

K-space

\[ e^{-x^2/2Dt} \quad e^{-1/2Dt} \]

Total Attenuation:

\[ S/S_0 = e^{-D\int k^2 dt} = e^{-bD} \]

where: \[ b = \int k^2 dt \]

Diffusion Imaging

Anatomy
Acoustic Waves
Stiffness
Taouli et al, AJR 2009; 193:14–27

Magnetization Transfer

Spin Exchange or Chemical Exchange

MT Ratio

Image Credit: http://commons.wikimedia.org/wiki/File:Conformational_states_of_PPDK.png
The equation shown) shows the linear dependence of GluCEST on pH in the physiological range (pH 6.0–7.4). (Fig. 1). There is a ~700-fold sensitivity amplification compared to bulk water signals. GluCEST varies linearly with pH in the physiological range (pH 6.0–7.4) (Fig. 2). The CEST contrast is color-coded on the original CEST image (3 p.p.m.), acquired with a saturation pulse train with B_1^+ field. Increased GluCEST (%) was observed (Fig. 3). Potential contributions from other brain metabolites have been investigated. The CEST properties from each of these metabolites in the bulk water have been characterized. Lesion detection in MS and white matter disease and holds continuing promise.

The CEST effect at 3 p.p.m., as well as their difference spectrum (blue line). (Fig. 4). The overlay of the single voxel shown in the CEST image (3 p.p.m.) and the CEST contrast color-coded on the original CEST image (3 p.p.m.), acquired with the application of saturation pulse train with B_1^+ field. Increased GluCEST (%) was observed as pH increased from pH 3 to pH 6 and then sharply decreased. The difference spectrum is shown, as well as their difference spectrum (blue line). (Fig. 5).

**Summary**

- **Movies**
  - MRA, Elastography: Phase Contrast
  - Cardiac: Tagging, Movies
  - Diffusion: Phase Dispersion

- **MRA, ASL: TOF**
  - MT and CEST: Exchange