Bioengineering 278  
Magnetic Resonance Imaging  

Winter 2011  
Lecture 9

- Motion Encoding using Longitudinal Magnetization:
  - Magnetic Resonance Angiography
  - Time of Flight
  - Contrast Enhanced
- Arterial Spin Labeling
  - ASL Basics
  - ASL for fMRI
  - Velocity Selective ASL
  - Vessel Encoded ASL

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

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

\[
\text{Signal}(tr) = M_z(tr)\sin(\alpha)
\]
Contrast Enhanced MRA

- MRA acquired during the passage of a bolus of Gd based contrast agent
- $T_1$ reduced as low as 50ms
- $T_1$ is so short, no need to rely on TOF effect for contrast
- Allows for very short TR and high flip angle
- Dramatically improves speed and/or SNR
- After first pass, Gd leaks into tissues

4s per frame

http://www.mr.ethz.ch/sense/sense_application.html

GEMS web site

http://www.m.ehime-u.ac.jp/school/radiology/mra/3T-MRA.jpg
**Arterial Spin Labeling**

Tag by Magnetic Inversion

Control

Acquire image of tissue + relaxed blood

Acquire image of tissue + tagged blood

Inflow and T, Decay

ASL Signal = Control - Tag ∝ CBF

Tissue Signal subtracted out.

**Blood Water Dynamics**

Perfusion:
mL blood per 100 gram tissue per min

- Brain: 0.01s⁻¹
- Heart: 0.01s⁻¹
- Kidney: 0.01s⁻¹
- Lung: 0.01s⁻¹
- Skeletal Muscle: 0.001-0.01s⁻¹

Tissue Water

Arteries  Capillaries  Veins

0-10s  0.5-1s  ?

E. Wong, BE278, UCSD Winter 2011
Dealing with Tissue Signal

- **Pre-saturation (pre-sat):**
  - Saturation on the imaging slab

- **Back-Ground Suppression (BGS):**
  - Globally applied inversion pulses to null tissue signal

Types of ASL

- **CASL**
- **PASL**
- **VSASL**
**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:

$$\vec{B}_e = B_1 \hat{i} + \frac{\Delta \omega}{\gamma} \hat{k}$$
Transit Delay - PASL

\[ \Delta M = M_0 \left[ 1 - e^{-\frac{t}{T_1}} \right] \]

\[ \text{TI} < \Delta t : \quad \Delta M(TI) = 0 \]
\[ \Delta t < \text{TI} < \Delta t + \tau : \quad \Delta M(TI) = 2M_0(TI-\Delta t) \text{CBF} e^{-\frac{\text{TI}}{T_1B}} \]
\[ \Delta t + \tau < \text{TI} : \quad \Delta M(TI) = 2M_0(\tau) \text{CBF} e^{-\frac{\tau}{T_1B}} \]

Continuous vs Pulsed ASL

- **CASL**
  - Flow Dependent Inversion Plane
  - T_1 Decay

- **PASL**
  - Pulsed Inversion Slab
  - Imaging Plane

**CASL vs PASL**
- Larger ASL signal
- Higher SAR
Water Exchange

Good…

Not so good…

• $T_1$ shift changes relaxation rate of tag during TI
• $T_2/T_2^*$ shift changes ASL signal during image acquisition

For Pulsed ASL with Presat:
Control - Tag = ASL Signal
Control + Tag = Tissue Signal

E. Wong, BE278, UCSD Winter 2011
Simultaneous Flow and BOLD fMRI

Anatomy

CBF Change

BOLD Change

Transit Delays in Diagnostic ASL

• Problem:
  – Long transit delays (delay >> T₁) limit the diagnostic potential of ASL in some disease states

• Solution:
  – Apply tag pulses that are not spatially selective but velocity selective
Velocity Selective ASL

- Tagging based purely on velocity
- Tag has no spatial selectivity
- Transit delay eliminated

\[ T_1 = 1.6 \text{s} \]

Vessel Encoded Pseudo-Continuous ASL

\[
\begin{bmatrix}
  y_1 \\
  y_2 \\
  y_3 \\
  y_4
\end{bmatrix} =
\begin{bmatrix}
  -1 & 1 & -1 & 1 \\
  1 & -1 & -1 & 1 \\
  -1 & -1 & 1 & 1 \\
  1 & 1 & 1 & 1
\end{bmatrix} \begin{bmatrix}
  R \\
  L \\
  B \\
  S
\end{bmatrix}
\]
Vascular Mixing

Vessel Encoded ASL

- Explicit identification of territories with probabilities
- Nonlinear encoding
- Vascular Source Imaging

Multi-dimensional clustering