Motion Related Contrast in MRI

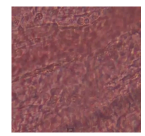
Eric Wong

Types of Motion in the Body

K.Nayak, USC

Gross

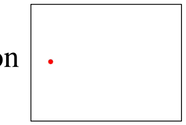
Cardiac



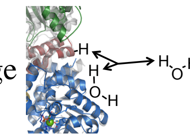
Blood Flow

Perfusion

Diffusion



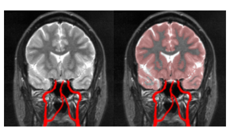
Exchange



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

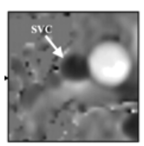
MR Tools for Encoding Motion

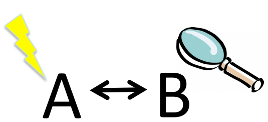
Cinematography



Time of Flight (M_Z, T_1)

Phase Contrast (M_{XY}, T_2)

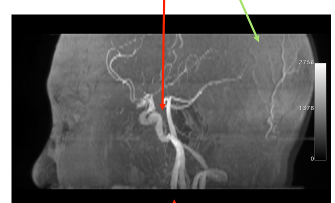


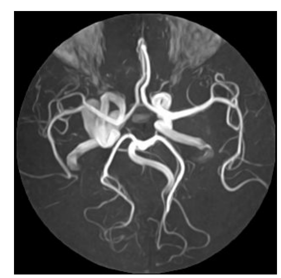


Indirect

Time of Flight MRA

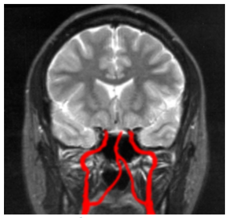
- Spoiled gradient echo with high flip angle and short TR
- Static magnetization becomes highly saturated
- Relaxed inflowing blood has much higher signal

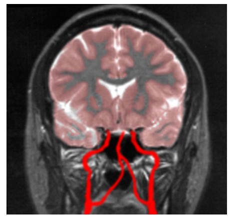




Relaxed
Blood Magnetization

Arterial Spin Labeling



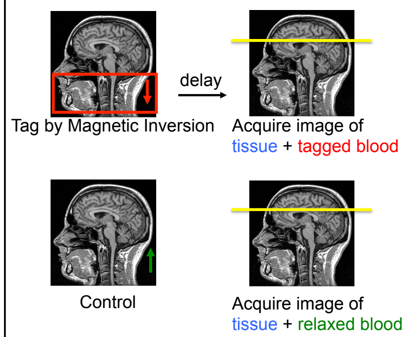


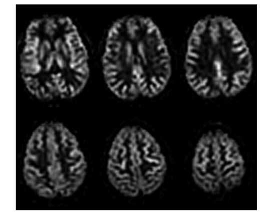
RF

- 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

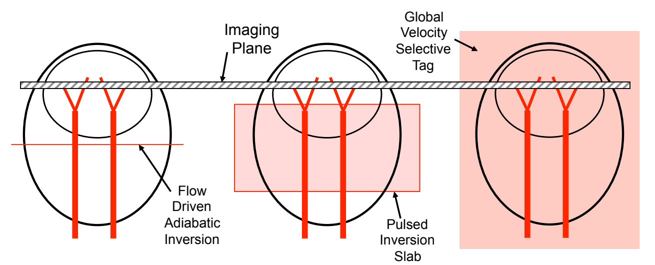
The ASL Measurement



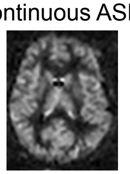


ASL Signal = Control - Tag ∝ Perfusion

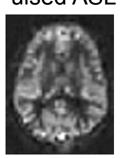
Classes of ASL Labeling Methods



Continuous ASL



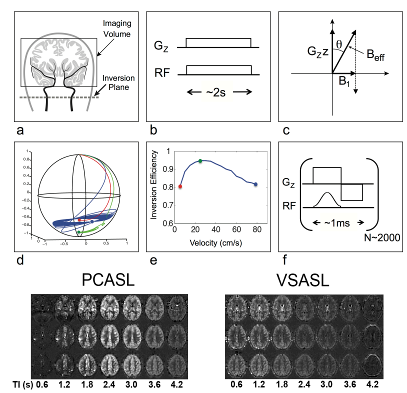
Pulsed ASL



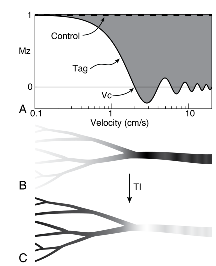
Velocity Selective ASL

ASL Labeling

Continuous/Pseudocontinuous



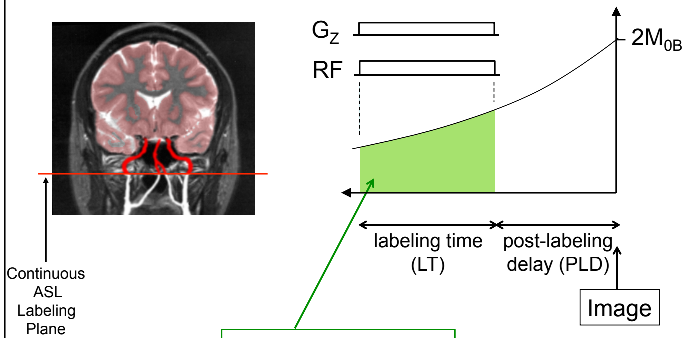
Velocity Selective



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

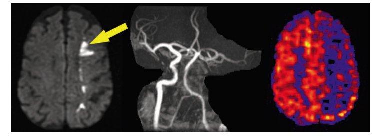
Jia Guo, UCSD

Calculation of CBF

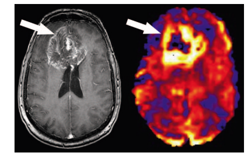


$$\Delta M_Z = (CBF)\,2M_{0B}\int_{PLD}^{PLD+LT} e^{-t/T_1}\,dt$$

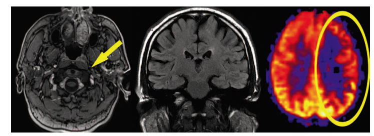
Clinical ASL



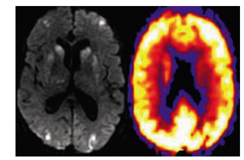
Ischemic Penumbra: Perfusion > Diffusion Mismatch



Glioblastoma Multiforme



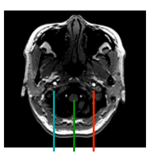
LICA Occlusion: Tissue at Risk

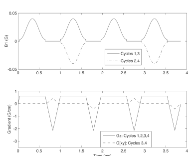


Hyperperfusion post anoxia

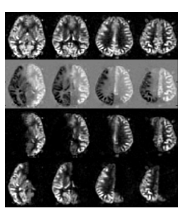
Wake Forest: Deibler et al, AJNR August 2008

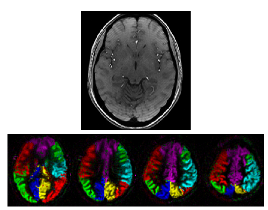
Vessel Encoded ASL (VEASL)



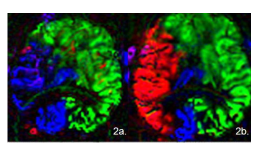


$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \end{bmatrix} = \begin{bmatrix} -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 \\ -1 & -1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} R \\ L \\ B \\ S \end{bmatrix}$$





Above the Circle of Willis



Pre and Post Stent

Cardiac MRI - Goals

Metric	MRI	Competing
Function - Ejection Fraction	Cine	Echocardiography
Function – Contractility	Myocardial Tagging	
Function - Valves	Cine	Echocardiography
Coronary Arteries	Gated TOF	Cardiac Catheterization
Perfusion	Gd Bolus, ASL	SPECT, PET, CT

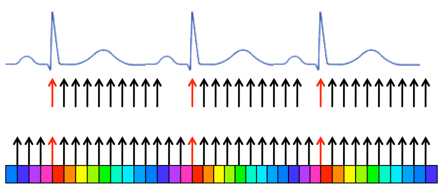
Main Challenge: MOTION

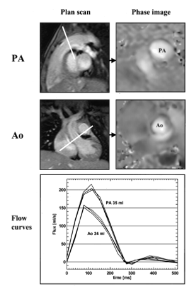
- Beating
- Respiration
- Patient

Gating

Prospective

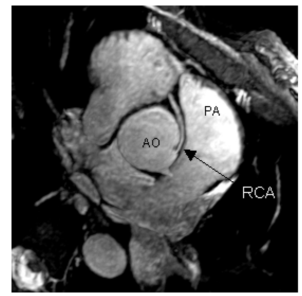
Retrospective

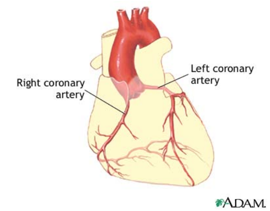


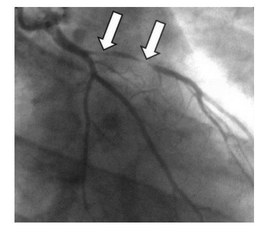


http://youtu.be/BhMFhbcp2Jg

Coronary Arteries

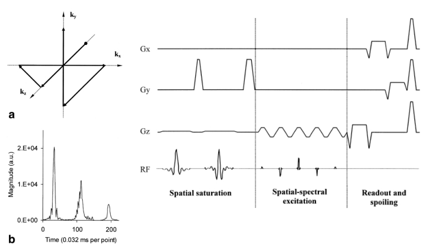


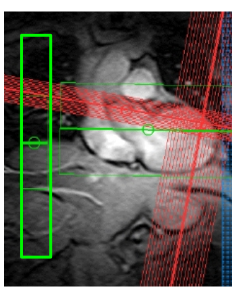


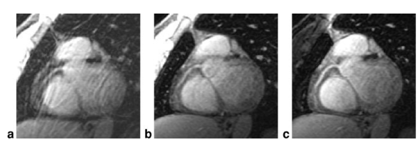


Gating/Navigation

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

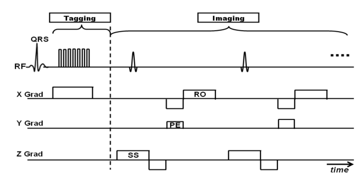




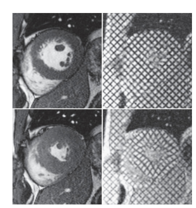


Gated, no nav +diaphragm nav +fat nav

Myocardial Tagging

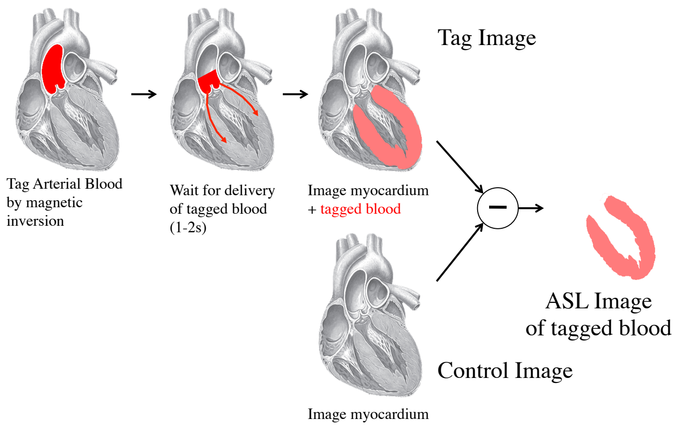


Ibrahim *Journal of Cardiovascular Magnetic Resonance* 2011 **13**:36
doi:10.1186/1532-429X-13-36

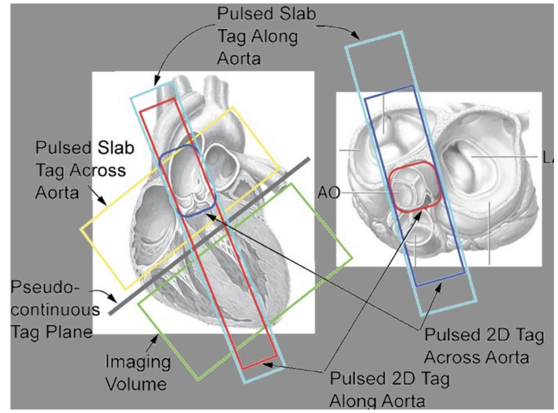


Aggarwal N R *et al.* (2009)
Nat Rev Cardiol doi:10.1038/nrcardio.2009.189

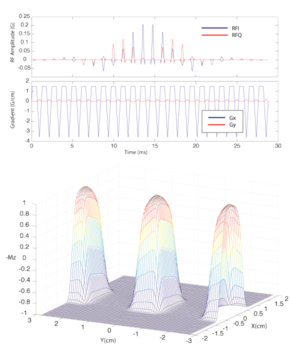
Arterial Spin Labeling

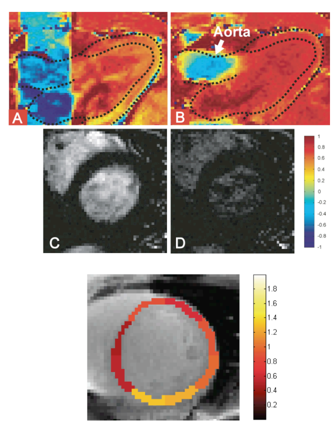


ASL Tagging Schemes



2D Pulsed Tagging





Break

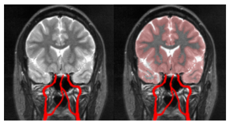
Plug for BE278: MRI Lab

Week	Lecture	Lab
1	Hardware Overview	Scanner Safety Collect 2D image data, reconstruct image
2	K-space	2D Spinwarp imaging Chemical shift SNR
3	Spin Echoes Gradient Echoes Coherence Pathways	Spin Echoes and Gradient Echoes Generate an interferogram
4	Fast Imaging	EPI, FSE and bSSFP
5	Excitation RF pulses	Design and test an RF pulse Spatial-Spectral Pulses
6	Motion Encoding	MRA, cardiac imaging
7	RF Coils	Build an RF coil
8-10	Final Projects	TBD

http://cfmriweb.ucsd.edu/ecwong/BE278W14.html

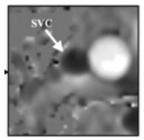
MR Tools for Encoding Motion

Cinematography



Time of Flight
(M_Z, T_1)

Phase Contrast
(M_{XY}, T_2)



A ↔ B

Indirect

Encoding M_{XY} for Motion: Phase Contrast

Phase from Motion:

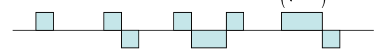
$$\omega = \gamma B$$

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

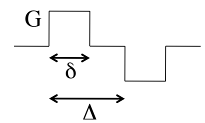
$$= \int \gamma \vec{G}(t) \bullet \vec{r}(t)\,dt$$

$$= \int \gamma \vec{G}(t)(\vec{r}_0 + \vec{V}t + \ldots)\,dt$$

$$= \vec{r}_0 \bullet \underbrace{\int \gamma \vec{G}(t)\,dt}_{\text{Zeroth Moment } (m_0) = k} + \vec{V} \bullet \underbrace{\int \gamma \vec{G}(t)\,t\,dt}_{\text{First (flow) Moment } (m_1)} + \ldots$$



Bipolar Gradient:



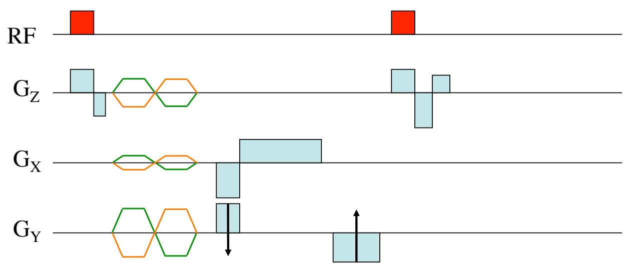
$$m_1 = \gamma G \delta \Delta$$

How Big can m_1 be?

For: G=4G/cm
δ=Δ=50ms

- π per 6μm
- VENC=velocity for ϕ=π
=6μm/50ms=0.12mm/s

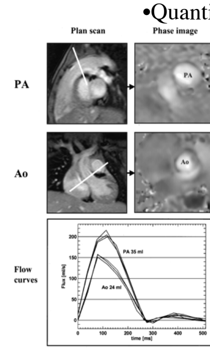
Phase Contrast MRA



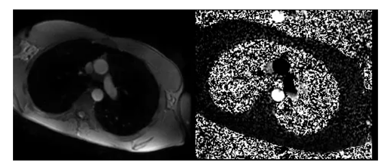
- •One image with velocity encoding positive
- •One image with velocity encoding negative
- •Vector sum of gradients determines direction of encoding
- •Display phase difference between images
- •Phase difference subtracts out off-resonance and other phase effects

Phase Contrast MRA

- •Phase proportional to velocity
- •Quantify velocity from phase images

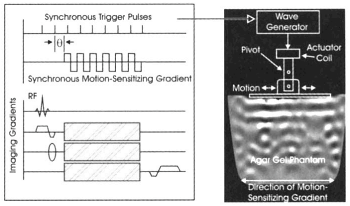


Bushberg: The Essential Physics of Medical Imaging, 2002.

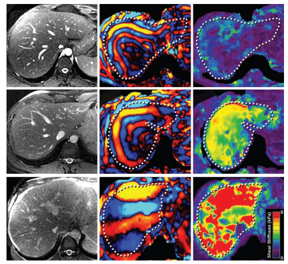


Magnitude Phase

MR Elastography

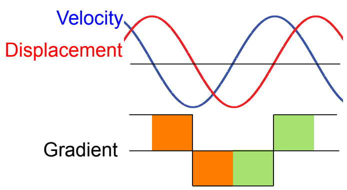


Muthupillai et al, Nature Medicine 2 (5) 1996



Anatomy | Acoustic Waves | Stiffness

Taouli et al, *AJR 2009; 193:14–27*



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:

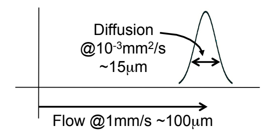
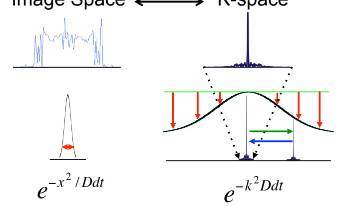
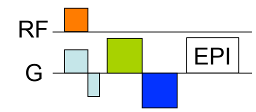


Image Space $\xleftrightarrow{FT}$ K-space



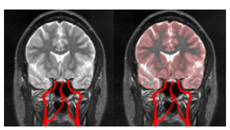
Pulse Sequence



Total Attenuation: $S/S_0 = e^{-D\int k^2 dt} = e^{-bD}$ where: $b \equiv \int k^2 dt$

MR Tools for Encoding Motion

Cinematography



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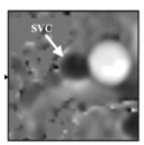
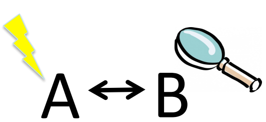
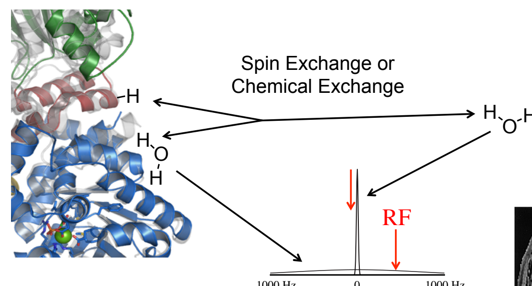
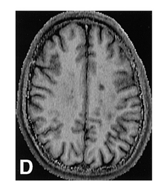




Indirect

Magnetization Transfer



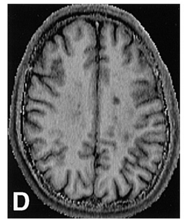


MT Ratio

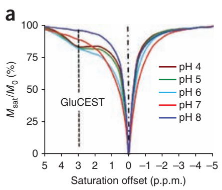
Image Credit: http://commons.wikimedia.org/wiki/File:Conformational_states_of_PPDK.png

Magnetization Transfer: Applications

Static tissue suppression for MRA
Henkelman et al, *NMR Biomed.* 2001;14:57–64



Lesion detection in MS
Pike G B et al. Radiology 2000;215:824-830



CEST:
Chemical Exchange
Saturation Transfer

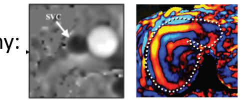
Cai et al. Nature Medicine **18**, 302–306 (2012)
doi:10.1038/nm.2615

Summary

K.Nayak, USC

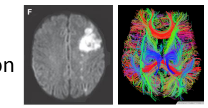
Movies

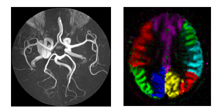
MRA, Elastography:
Phase Contrast



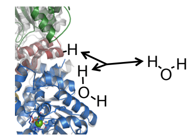
Cardiac:
Tagging,
Movies

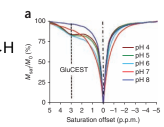
Diffusion:
Phase Dispersion





MRA, ASL: TOF





MT and CEST: Exchange