

Brain Functional Imaging: Alternatives to BOLD contrast

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Review

- NMR Signal
- MR Imaging
- MRI Contrast
- Functional MRI

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Physiology during Neural Activation

- **Neural Firing: Electric Activity**
EEG/ERP, MEG, TMS
- **Biochemical Reaction: Metabolic Activity**
PET, MRS
- **Vascular Response: Hemodynamic Activity**
PET, Optical Imaging, fMRI
 - Cerebral Blood Oxygenation: BOLD
 - Cerebral Blood Flow (CBF): Arterial Spin Labeling
 - Cerebral Blood Volume (CBV): Bolus Injection

BOLD Contrast Review

Blood has magnetic properties:

- Red blood cells: hemoglobin carries O_2
- Deoxy-hemoglobin is paramagnetic

So:

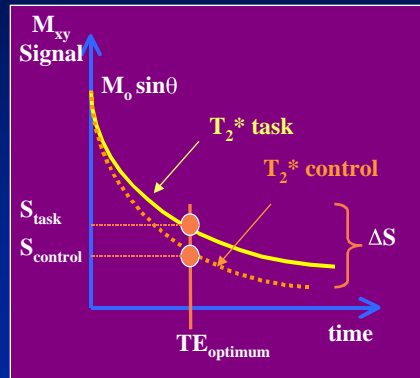
- **Neuronal activation changes**
- \Rightarrow Metabolic changes \Rightarrow **deoxy-hemoglobin changes**
- \Rightarrow Microscopic field gradient around vessels
- \Rightarrow T_2 and T_2^* changes (water inside/close to vessels)
- \Rightarrow **Signal changes in T_2 / T_2^* weighted MRI**

BOLD: complex function of CBF, CBV, $CMRO_2$

BOLD Contrast Review

Summary: if activation \uparrow then MR signal \uparrow
in T_2 / T_2^* weighted MRI

Blood flow	$\uparrow \uparrow \uparrow$
O ₂ utilization	\uparrow
Blood O ₂ level	$\uparrow \uparrow$
Deoxy-hemoglobin level	$\downarrow \downarrow$
Distortions in B ₀ (B)	$\downarrow \downarrow$
Phase dispersal of M	$\downarrow \downarrow$
Effective transverse relaxation (T_2^*)	$\uparrow \uparrow$
T_2^* -weighted signal	$\uparrow \uparrow$



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BOLD Review: Spatial Resolution

- Both T_2 and T_2^* changes detect BOLD changes
- But signal comes from different spins populations
 - T_2^* effects: dephasing from static + dynamic ΔB
 - T_2 effects: dephasing from dynamic ΔB

Red blood cell

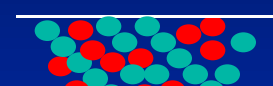


Water diffusion path

Capillary



Large blood vessel



Diffusion path $>$ gradient difference
 \Rightarrow spin 'feels' dynamic $B(T_2)$

Diffusion path \ll gradient difference
 \Rightarrow spin 'feels' static $B(T_2^*)$

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BOLD: GE vs SE fMRI

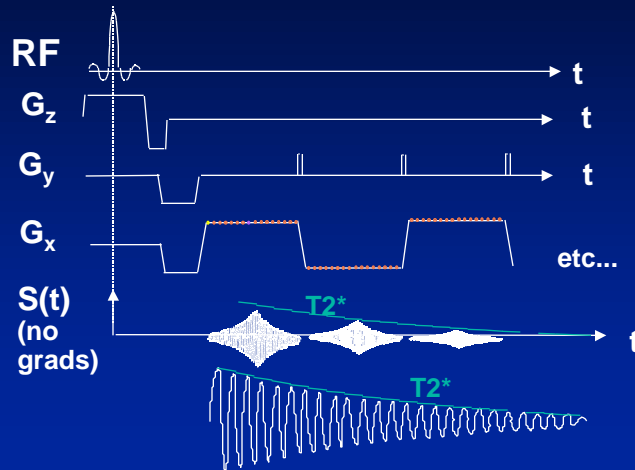
- **T₂-weighted fMRI**
 - insensitive to macroscopic extravascular component
 - sensitive to microscopic extravascular component
 - sensitive to intravascular components all vessels
- **T₂*-weighted fMRI**
 - sensitive to extravascular components all vessels
 - sensitive to intravascular components all vessels

BOLD: GE vs SE fMRI

- **Spin-Echo** theoretically more spatially precise than Gradient-Echo
(because large vessels downstream from activation don't contribute to signal changes)
- But, **Spin-Echo** has a lower magnitude response (factor of 5 or more)

BOLD: The MRI Sequence

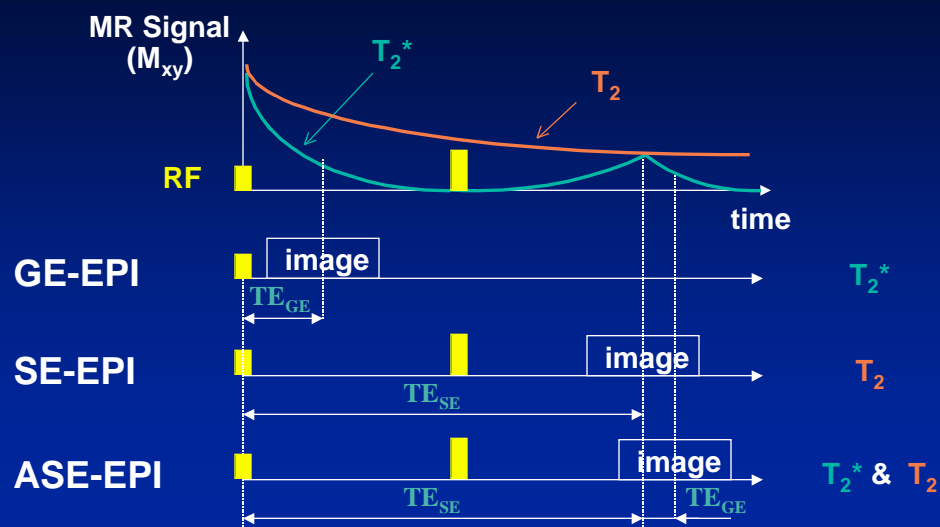
Echo Planar Imaging (EPI)



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BOLD: using EPI



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BOLD vs Perfusion fMRI

- BOLD signal reflects changes in local [deoxy-Hb]
- BOLD signal depends on: CBF, CBV, CMR_{O_2}
- Perfusion (CBF): rate of delivery of metabolic substrates
- Regional ΔCBF closer to neural activity than $\Delta BOLD$
- **Perfusion fMRI: potential for better spatial localization potentially absolutely quantitative**
- **However: less sensitive + lower temporal resolution**

MR Perfusion: Arterial Spin Labeling (ASL)

MOTIVATION:

Measure flow changes directly ...

i.e., images of blood water that
flows into the capillary bed AND
exchanges into the tissue

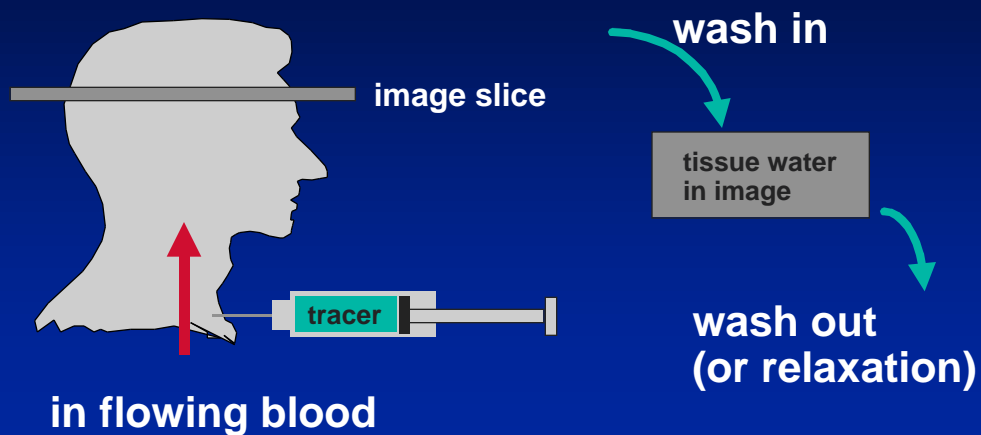
Arterial Spin Labelling Techniques

- Track a bolus of exogenous tracer
 - paramagnetic contrast agent
 - intra-vascular, non diffusible
- Track 'magnetically labelled' water
 - non-invasive

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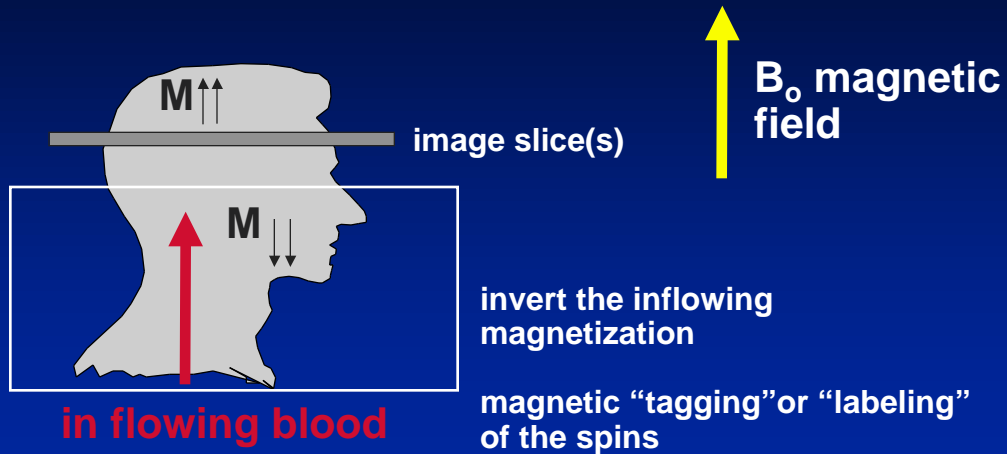
Arterial Spin Labeling (ASL) Perfusion Sequences (magnetic tracers)



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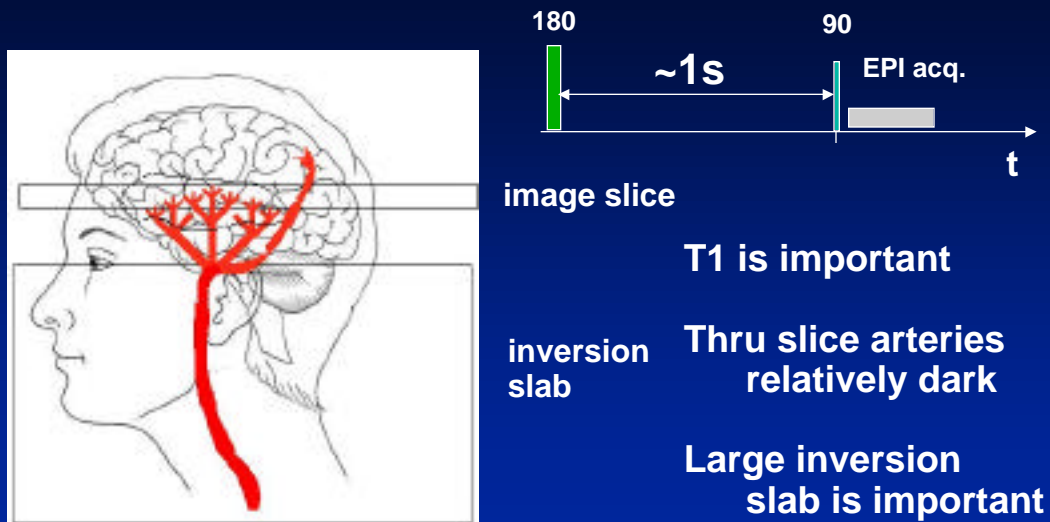
How to create a magnetic tracer: Arterial Spin Labeling



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Pulsed ASL: The Label



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Arterial Spin Labelling

- Perfusion image = control image - labelled image
- Perfusion signal changes < 3% intensity reduction
- Averaging to improve SNR:
control - label - control - label - control - label - ...
⇒ lower temporal resolution than BOLD
- Motion: big problem

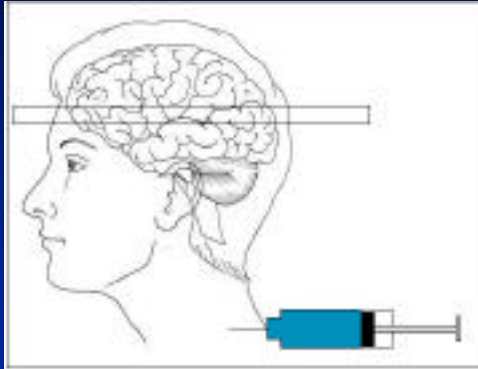
Direct measurement of CBV for fMRI

MOTIVATION:

If CBF and CBV measured independently

⇒ estimation of $CMRO_2$

Bolus Gd(DTPA) MR CBV (Intravascular T2* agent)



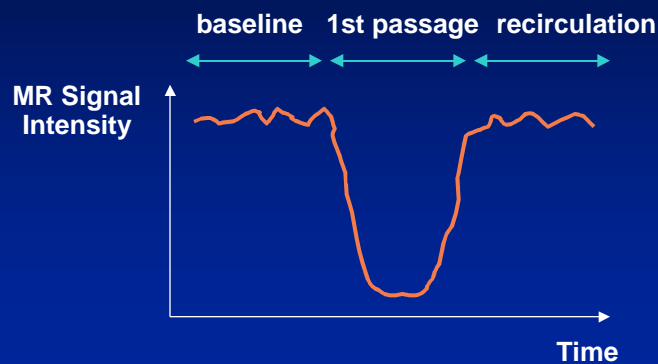
- Agent stays in brain vessels
- Susceptibility effects
⇒ $\downarrow T_2^* \Rightarrow$ signal drop
- Signal drop
⇒ concentration agent
- Integral of concentration
timecourse \propto rCBV

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CBV: Bolus tracking

Signal time course in perfused voxel

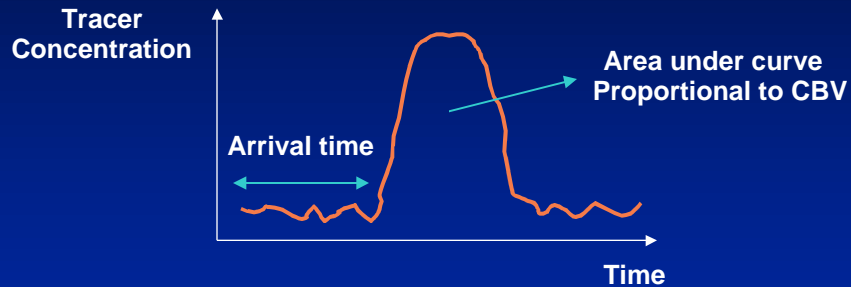


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CBV: Bolus tracking

Concentration time curve in perfused voxel



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Summary: Brain fMRI Contrasts

- **BOLD**: the most sensitive, but complex link to sources of neural activation
- **Alternatives to BOLD**: CBF, CBV, CMRO₂
- **Alternatives to BOLD**:
 - used for better understanding BOLD
 - for complement BOLD, potentials, less sensitivity
 - under development

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