PHYSICS OF MRI ACQUISITION

- Quick Review
- Alternatives to BOLD for fMRI

HST-583, Fall 2002

Quick Review of Concepts

- NMR Signal
- MR Imaging
- MRI Contrast
- Brain Functional MRI
  - Goal: Detect neural activation
  - BOLD method

Physiology during Neural Activation: Quick Review

- **Neural Firing: Electromagnetic Activity**
  Detection: EEG, MEG
- **Biochemical Reaction: Metabolic Activity**
  Detection: PET, MRS
  - cerebral metabolic rate of oxygen utilization ($CMRO_2$)
- **Vascular Response: Hemodynamic Activity**
  Detection: PET, Optical Imaging, ***fMRI***
  - cerebral blood flow (CBF)
  - cerebral blood volume (CBV)

Alternatives to BOLD: Motivation

- What does BOLD detect?
- Changes in [deoxy-Hgb]:
  - changes in: CBF + CBV + $CMRO_2$
- Strong effects but limited physiological interpretation
- Independent measures of:

  CBV, CBV and $CMRO_2$ would be better

Alternative to BOLD: Perfusion MRI

- **Techniques that measure vascular parameters:**
  - ***CBF:*** **rate at which blood flows through the microvasculature of a region of tissue.**

    Unit: ml / g tissue / sec

    (~50 in gray matter, ~20 white matter)
    Independent of MRI technique.
  - **CBV: fraction of volume of tissue occupied by blood (~3%).**

    Dependent of MRI technique (sensitivity to vessel size)
  - ***MTT:*** **Mean transit time, average time that blood spends passing through the blood volume with a region of tissue before it exits though the venous system.**

Perfusion MRI

- **Fundamental Principle**
  - A paramagnetic tracer goes through a capillary network
  - Transient changes in local magnetic fields of surrounding tissue
  - Transient changes in the MR signal
  - MR signal changes vary rapidly: need fast MRI
  - MR signal time course

    ➡ concentration-time course (of tracer in tissue)

    ➡ tissue hemodynamic parameters

Perfusion MRI

- **Mainstream Approaches**
  - Bolus injection of magnetic contrast agent
  - *Arterial Spin Labeling (ASL): blood as tracer*
- **Potential Applications in Brain**
  - Blood flow in resting state:
    - Cerebrovascular disease, tumor characterization, monitoring drug effects, etc.
  - *Blood flow during activation:*
    - quantification, complements BOLD

} Area of research

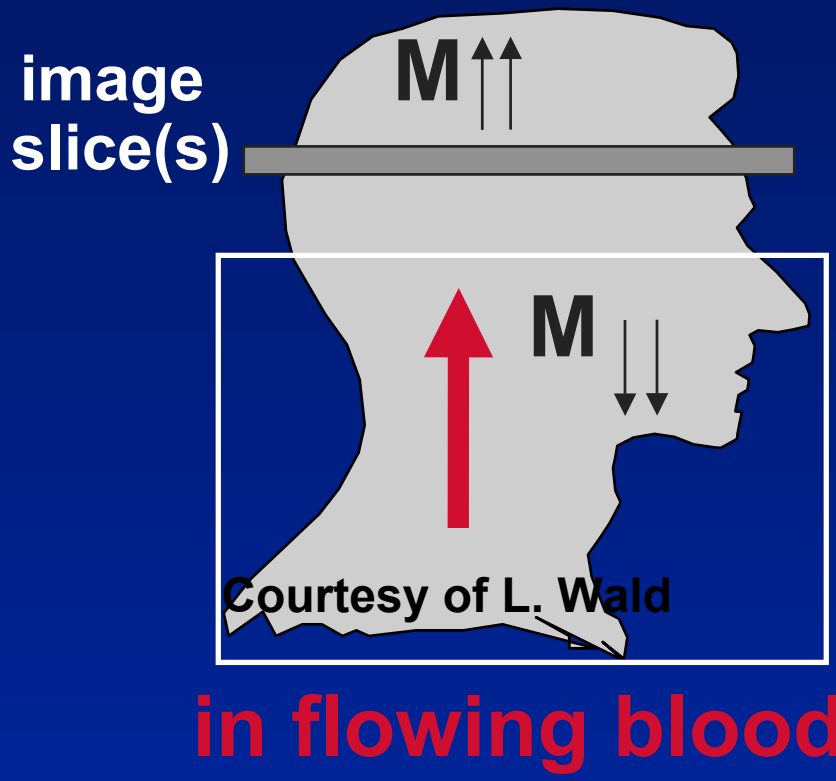
Strengths of ASL

- **Relative to bolus method**
  - no contrast agent required
  - reduced cost, discomfort
  - no limit to number of scans
  - temporal resolution of seconds
- **Relative to BOLD**
  - provide absolute measure of blood flow
  - more statistical power for low frequencies*
  - less variability across subjects*
  - less sensitive to susceptibility

**Aguirre et al., NeuroImage 2002*

Arterial Spin Labeling in Brief

B_o magnetic field

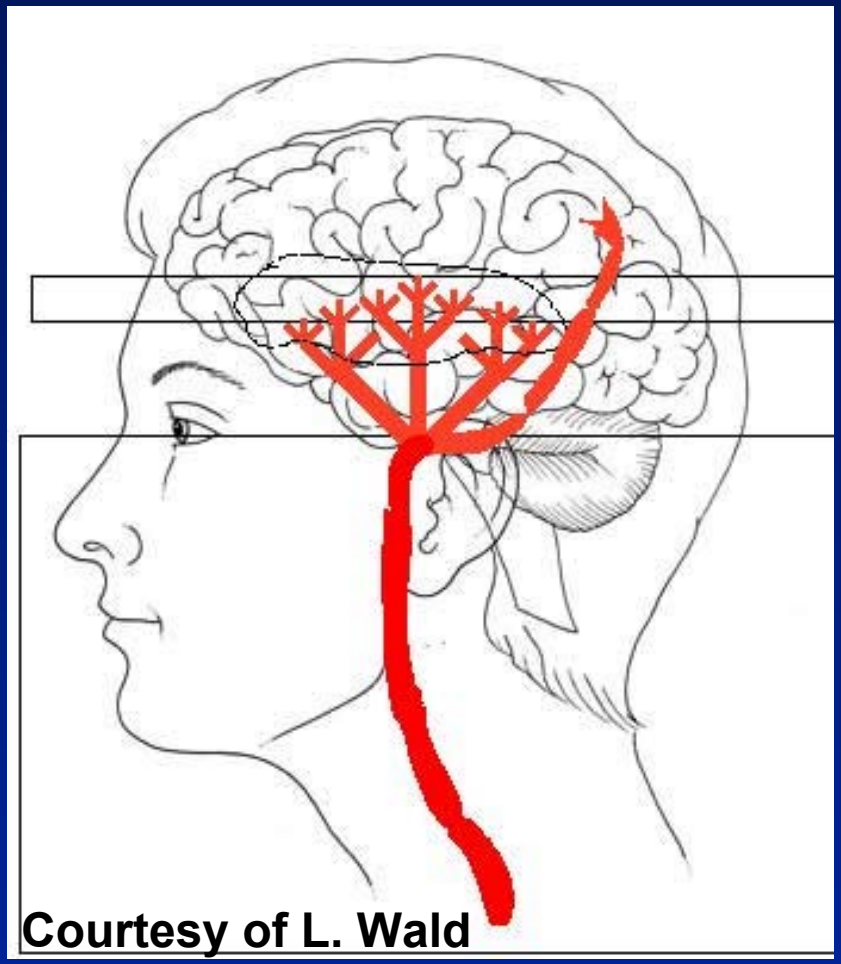


- **Tracer:** water in blood
- **Labeling:** invert inflowing magnetization
- **Life time:** T_1 of blood water (~1s)
- Labeled water flows into capillaries and exchanges with tissue water
- Inverted arterial inflow reduces total tissue magnetization in slice (~1%)
- Subtraction from a control image gives image proportional to CBF
- Theory can relate the ASL signal with absolute blood flow

Arterial Spin Labeling Strategies

- **Pulsed ASL**
  - Labeling is achieved by a short RF pulse that inverts the magnetization in a slab of tissue
- **Continuous ASL**
  - Labeling is achieved continuously as water spins flow past a plane defined by the location where a continuous RF B1 field is resonant

Pulsed ASL: The Label



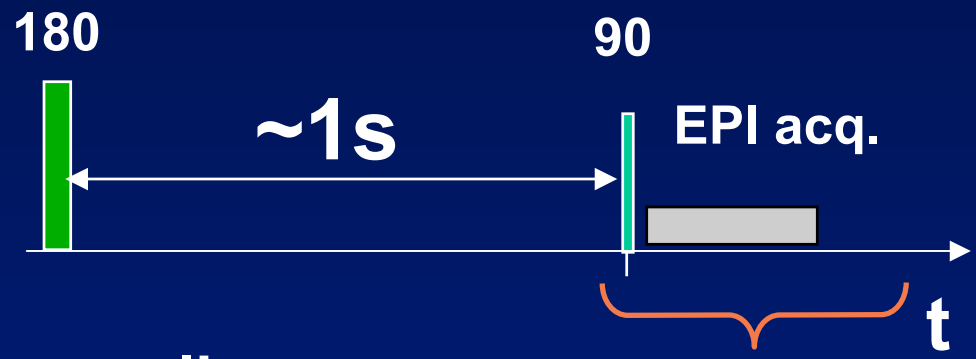


image slice

B_0 insensitive sequences can be used

inversion slab

- T1 is important
- Thru slice arteries relatively dark
- Large inversion slab is important

Simultaneous BOLD + perfusion fMRI possible

Arterial Spin Labeling

- Perfusion image = control image - labeled image
- Perfusion signal changes < 3% intensity reduction
- Averaging to improve SNR:
  control - label - control - label - control - label - …
  $\Rightarrow$ lower temporal resolution than BOLD
- Motion: big problem (subtraction errors)

BOLD and Perfusion fMRI: Temporal Stability

Estimated SNR vs stimulus frequency

See Aguirre et al., NeuroImage 2002

Within subject experimental design:

- **BOLD greater SNR for most stimuli frequencies**
- **Due to low noise at low low frequencies, perfusion might be better for experimental designs in which low frequencies predominate**

ASL Sensitivity Across Subjects

- **Small signal changes**
  - But better than BOLD for long time scales
  - But maybe better across subjects (more consistent)

- **SNR increases more rapidly with field strength than BOLD**
  - BOLD TE's must be shortened
  - T1 lengthening increases ASL signal

Average t-values

See Aguirre et al., NeuroImage 2002

ASL: Limitations

- Short life time of label due to T1
  - Low SNR: limits spatial resolution
- Dependence on arrival times and exchange times
- Oblique flowing blood vs assumption of upwards flow
- Accurate measurements of arterial blood T_1 and M_0 for absolute quantification
- No CBV obtained

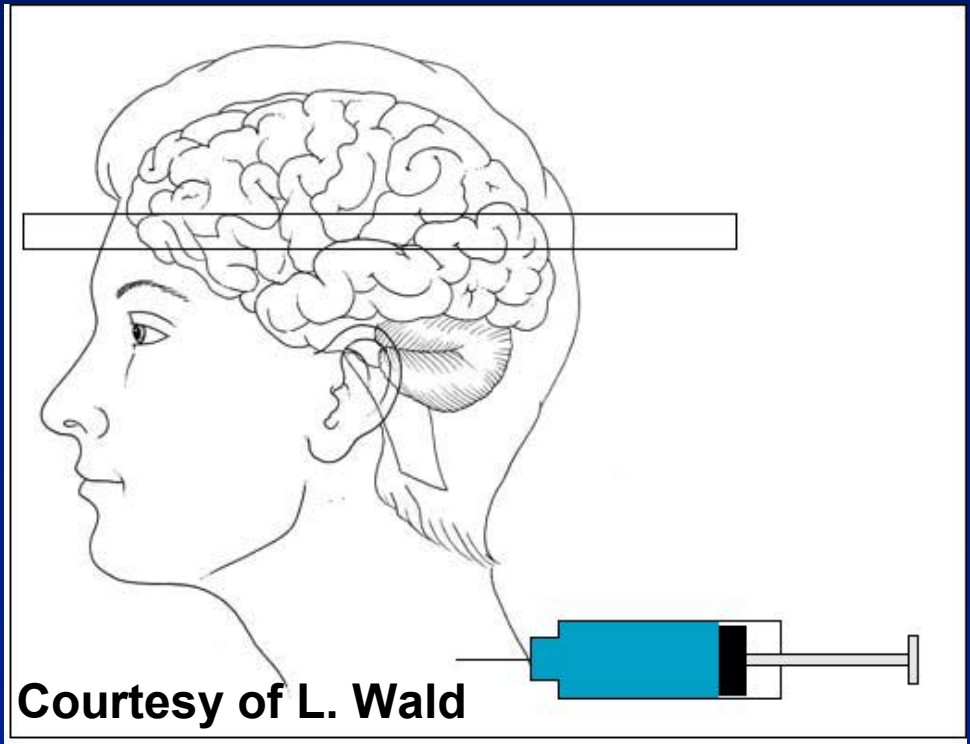
Direct measurement of CBV for fMRI

- **MOTIVATION:**

  If CBF and CBV measured independently

  $\Rightarrow$ estimation of $CMRO_2$

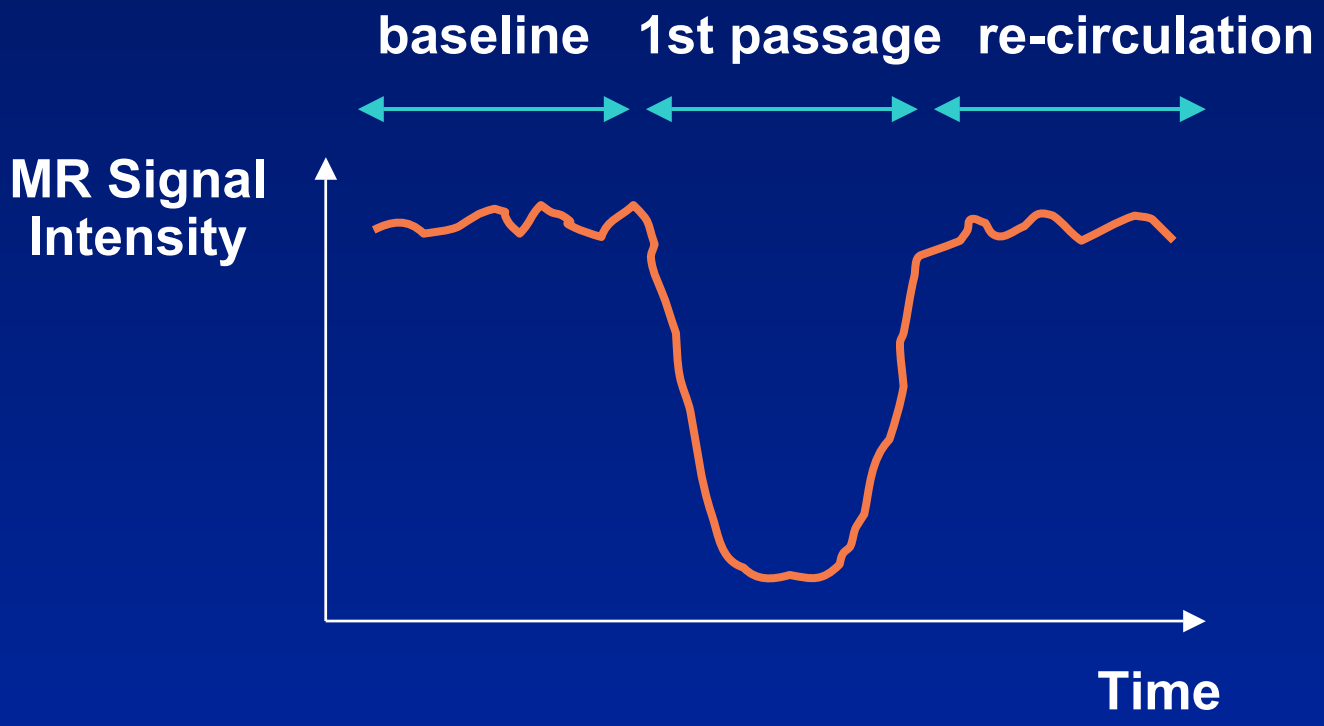
Bolus Gd(DTPA) MR CBV (Intravascular T2* agent)



- Agent stays in brain vessels
- Susceptibility effects
  $\Rightarrow \downarrow T_2^* \Rightarrow$ signal drop
- Signal drop
  $\Rightarrow$ concentration agent
- Integral of concentration time course proportional to rCBV

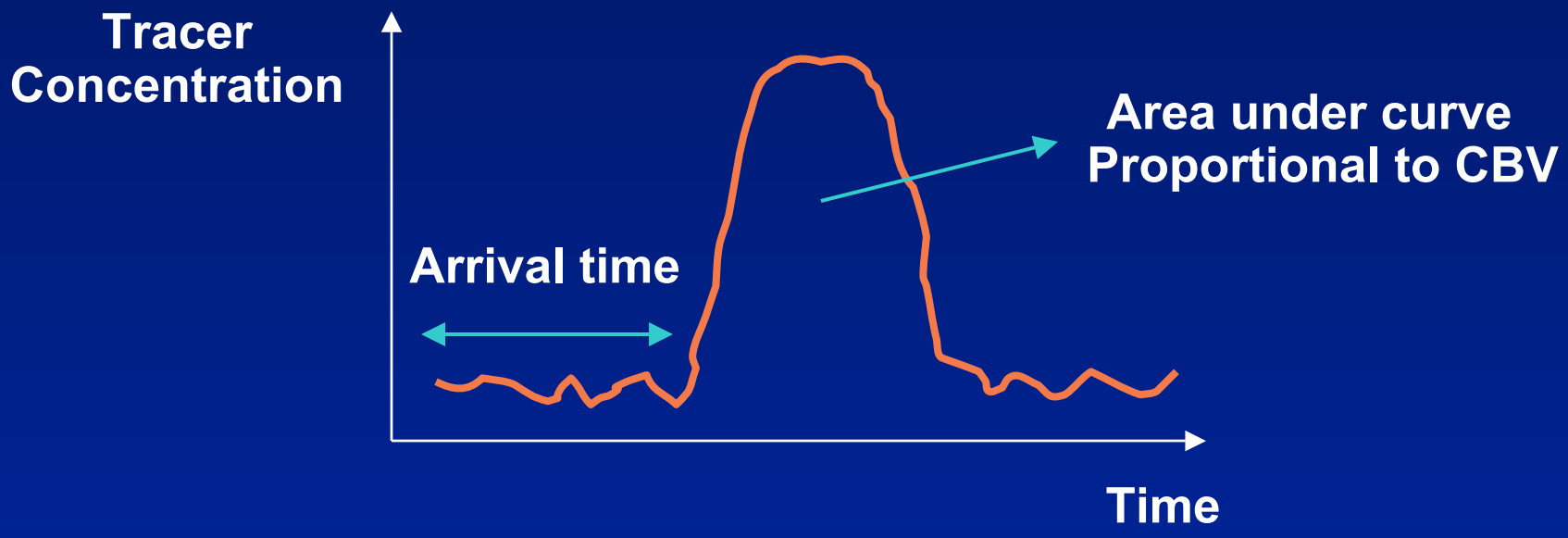
CBV: Bolus tracking

Signal time course in perfused voxel



CBV: Bolus tracking

Concentration time curve in perfused voxel



Summary: Brain fMRI Contrasts

- **BOLD:** The most sensitive, but complex link to sources of neural activation
- **Alternatives to BOLD:**
  - CBF, CBV, $CMRO_2$
  - Used for better understanding and complement BOLD
  - More direct assessment of vascular response
  - Less sensitive, under active development
- **Hopes for the future:**
  - Perfusion quantification improvements
  - Less motion sensitivity
  - Wider availability

More in: http://www.ujf-grenoble.fr/ismrm/ASL/outline.htm