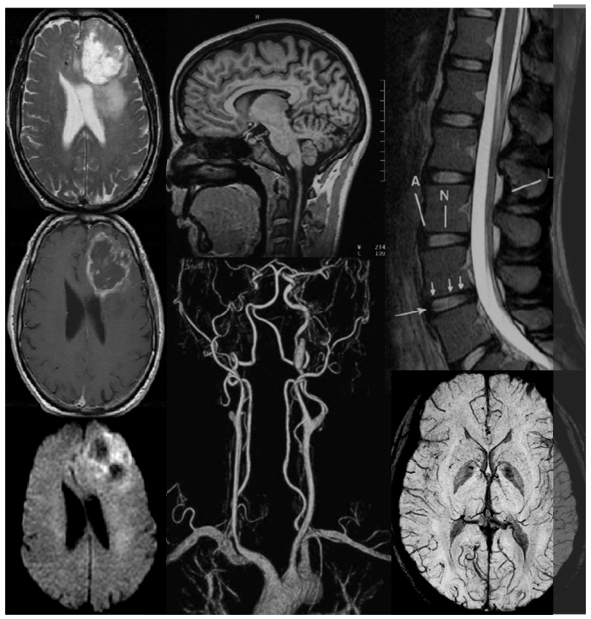

Magnetic Resonance in Medicine
Perfusion-Weighted Imaging (ASL)

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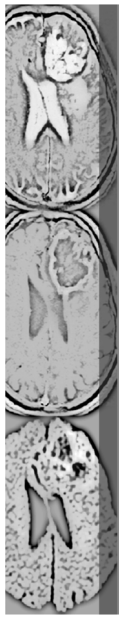
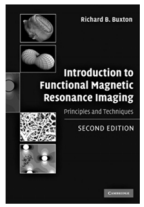
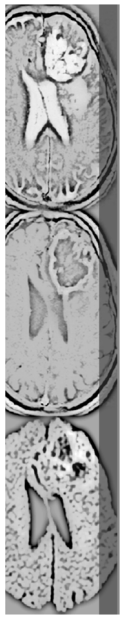


Content http://cflu.lab.nycu.edu.tw/

- Arterial Spin Labeling (ASL) 動脈自旋標記影像

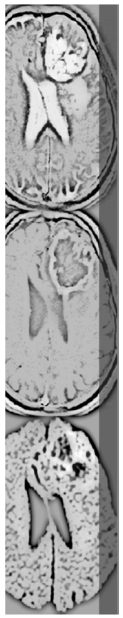
- Introduction to Functional Magnetic Resonance Imaging (2nd edition)
  - Chapter 13: Arterial spin labeling techniques



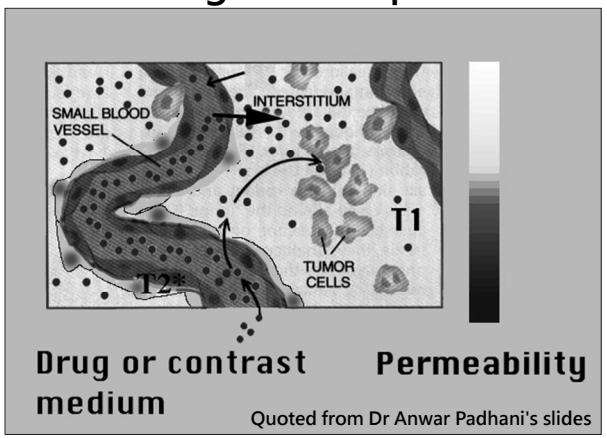


Perfusion imaging

- The information on the capillary microcirculation of tissue
- Three major techniques
  - Dynamic susceptibility contrast (DSC) MRI
  - Dynamic contrast enhancement (DCE) MRI
  - Arterial spin labeling (ASL) MRI
- Quantitative measurements
  - Blood volume (BV)
  - Blood flow (BF)
  - Temporal data (MTT)
  - Parameters of the pharmacokinetic model (K_{trans}, vp, ve, K_{ep})



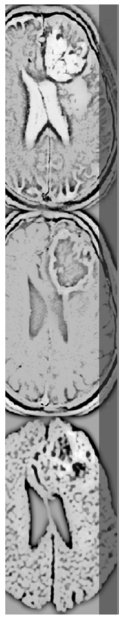
Contrast agent and permeability



How about water molecules?
- H_2O^{15} PET for cerebral blood flow
- A diffusible tracer
- Not capable in detecting vascular permeability

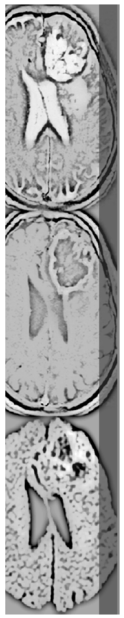
Arterial Spin Labeling, ASL

動脈自旋標記影像



Contrast in ASL

- Arterial water: a freely diffusible tracer
  - [vs.] the intravascular contrast agent (Gd-DTPA) used in DSC imaging.
  - Bypassing the concerns regarding nephrogenic systemic fibrosis (NSF)
- Provide a direct measurement of cerebral blood flow (CBF)
  - CBF is the fundamental physiological quantity.
  - Closely related to brain function.

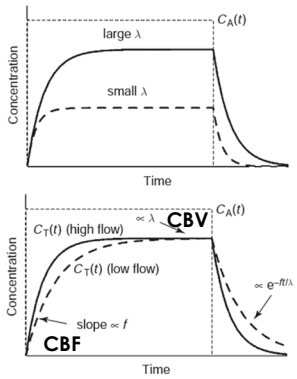


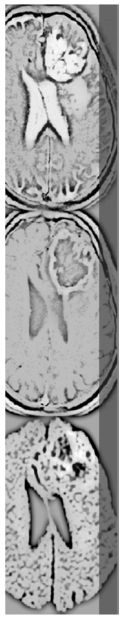
Cerebral Blood Flow (CBF)

CBF = Perfusion
= Rate of delivery of arterial blood to a capillary bed in tissue.

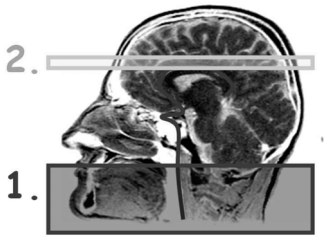
Units: $\frac{\text{(ml of Blood)}}{\text{(100 grams of tissue)(minute)}}$

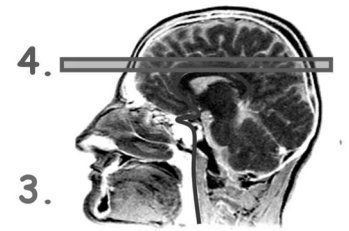
Typical value is 60 ml/(100g-min)





Principle of ASL

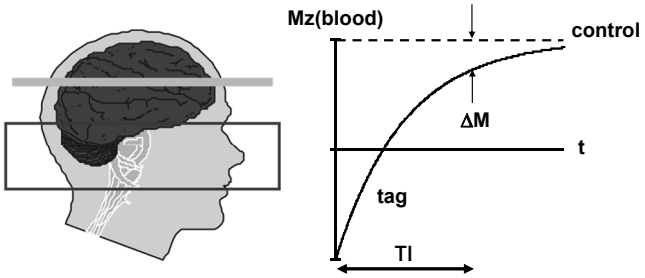




1. **Tag** inflowing arterial blood by magnetic inversion
2. Acquire the **tag image**
3. Repeat experiment without tag
4. Acquire the **control image**

http://fmri.research.umich.edu/research/main_topics/asl.php

Tagged signal changes

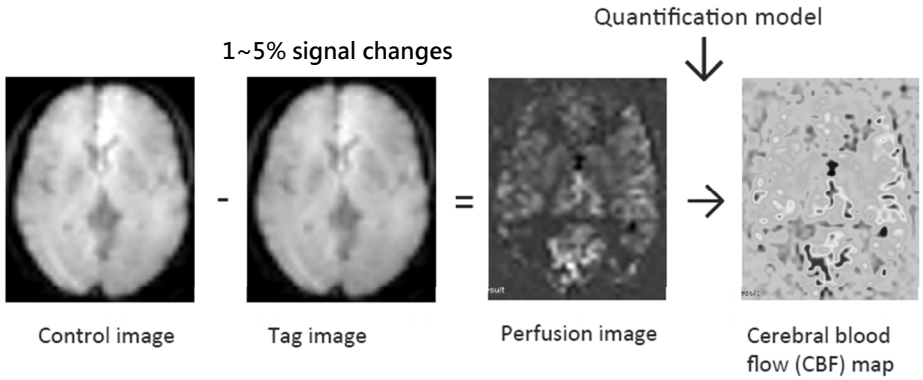


A_{eff} is the effective area of the arterial bolus. It depends on both physiology and pulse sequence parameters.

$$\Delta M = CBF \cdot A_{eff}$$

Adapted from Wen-Ming Luh

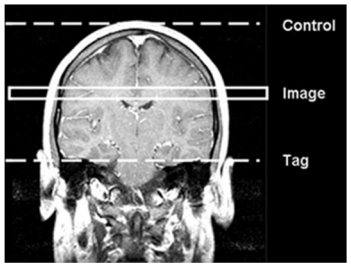
Principle of ASL



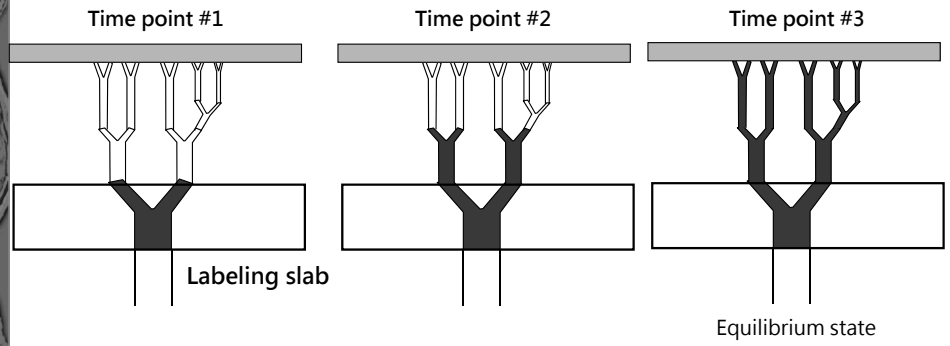
Adapted from Jean-Yves Gauvrit

Procedure of ASL

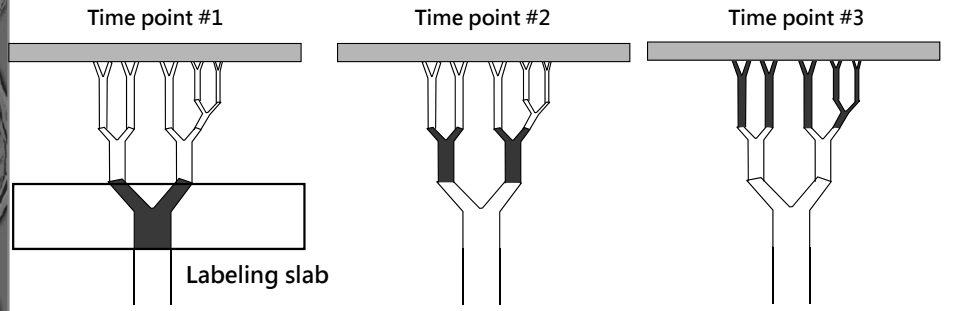
- Magnetically tag inflowing arterial blood
- Wait for tagged blood to flow into imaging slice (inversion time, TI)
- Acquire image of tissue+tagged blood
- Apply control pulse that doesn't tag blood
- Acquire control image of tissue
- Control image-tag image = blood image



Arterial Spin Labeling - continuous



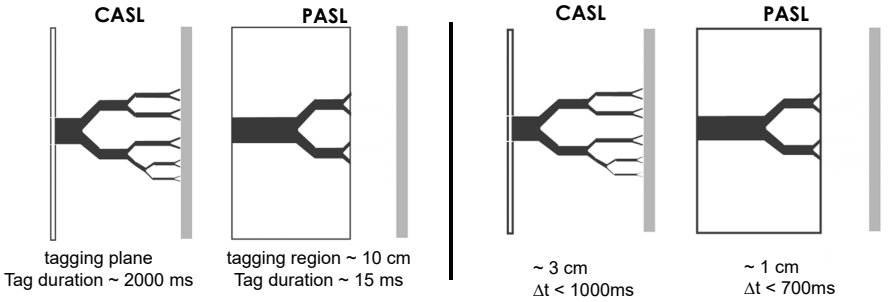
Arterial Spin Labeling - pulsed



Have to ensure the imaging time point is sufficient for the inflow of labeled blood

ASL Techniques

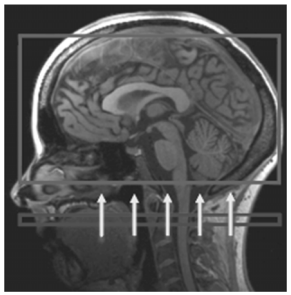
- **CASL**: continuous arterial spin labeling
  - continuously tags blood as it passes through a thin tagging plane
- **PASL**: pulsed arterial spin labeling
  - tags blood in a large slab proximal to imaging slice



Adapted from Wen-Ming Luh

Continuous ASL (CASL)

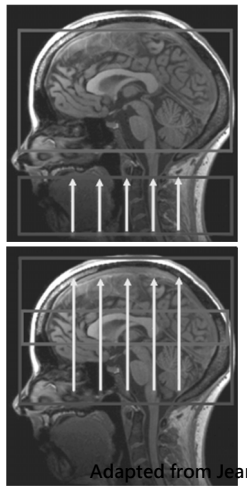
- Historical method
- Continuous (2-4s) and selective labeling of protons going through a tagging plane with an equilibrium state.
- Advantages
  - Higher SNR (compared to PASL)
  - Reliable CBF quantification
- Disadvantages
  - High SAR and magnetization transfer effects



Adapted from Jean-Yves Gauvrit

Pulsed ASL (PASL)

- Labeled by wide but short RF pulses
  - Upstream slab: STAR, QUIPPS, Q2TIPS
  - Over the whole region of interest: FAIR
- Advantages
  - Easy implementation
  - Multi-channel coil
    - Parallel imaging possible
  - Mutli-TI possible (arterial transit time)
- Disadvantages
  - Arterial transit effects
  - Lower SNR

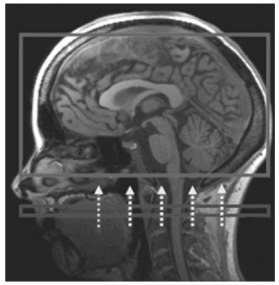


Adapted from Jean-Yves Gauvrit

Pseudo-continuous ASL (pCASL)

- Hybrid method
- Multiple short RF over an extended period

- Advantages
  - Improved SNR
  - Good reproducibility
  - Easy implementation



Adapted from Jean-Yves Gauvrit

Image Acquisition

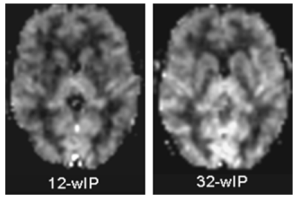
- Increase the number of acquisitions (labeled-control image pairs) to improve SNR, but increase the acquisition time
  - 30~50 measurements of image pairs (4 to 5 minutes)

- **2D Single-shot EPI**: most commonly used method
  - Satisfactory SNR and fast acquisition
  - May have image distortions
- **3D GRASE ASL**
  - Better SNR, shorter acquisition, and better coverage

Hardware Issues

- Increase the magnetic field
  - Increase intrinsic SNR
  - Better suppression of surrounding tissue
  - Increase the labeling duration (TI)
    - Blood T1: 1350 ms at 1.5T, 1650 ms at 3.0T

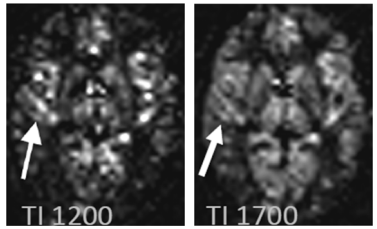
- Use of multi-channel coils
  - Possible with PASL and pCASL
  - 12 channels → 32 channels: SNR +39%
  - Parallel imaging possible



Ferre et al. JMRI 2012.

ASL artifacts

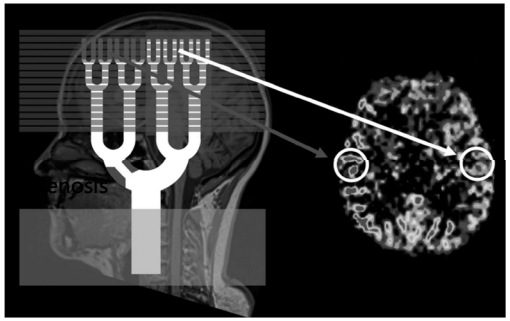
- Vascular artifacts
  - Increased CBF values at arterial or venous vessel locations
  - Due to the labeled blood in the vessels rather than in the tissues.
  - Affected by the arterial transit times



ASL artifacts

- Arterial Transit Delay Artifact
  - The prolonged arterial transit time can cause a less reduction in the ASL tagged images.

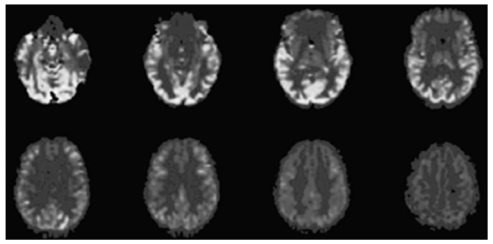
However, this effect by itself can not be used to infer the decreased CBF in local tissues!



Mutke et al. Plos One, 2014.

ASL artifacts

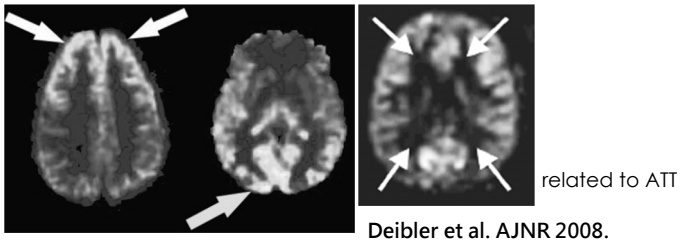
- Loss of signal in the upper slices
  - Related to the relaxation of labeled protons.
  - Caudo-cranial 2D, especially at 1.5T, reduced labeling time (TI)
  - Parallel imaging: decrease the acquisition time of slices and thus the time between slices.



Deibler et al. AJNR 2008.

ASL phenomenon

- Physiological hyperperfusion/hypoperfusion
  - (occipital lobes) Perhaps a reflection of heightened sensory stimulation in the MR environment
  - (prefrontal cortex) This pattern is believed to be a normal finding in young and middle-aged patients.



related to ATT

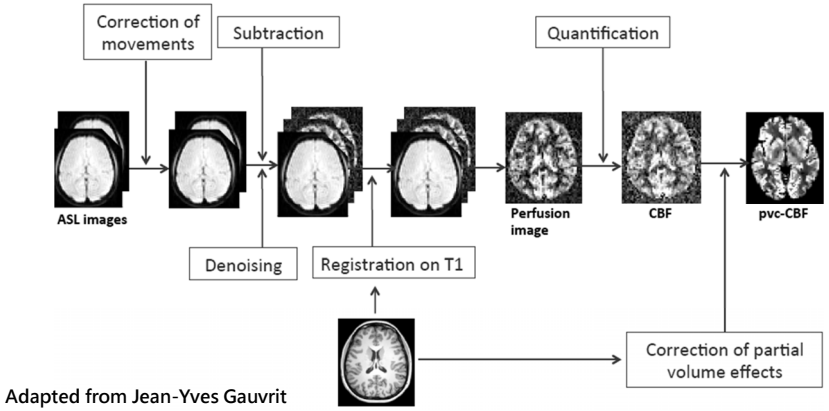
Deibler et al. AJNR 2008.

CBF Calculation

- Low intrinsic SNR: signal only 1 – 5% of mean MR **signal intensity**
- CBF calculation → intesity difference
- Critical preprocessing steps:
  - Motion correction
  - Spatial smoothing & normalization
  - Global spike elimination
  - Measure of global signal as covariate

ASL Data Processing Toolbox: ASLtbx
https://cfn.upenn.edu/perfusion/

Processing of ASL images

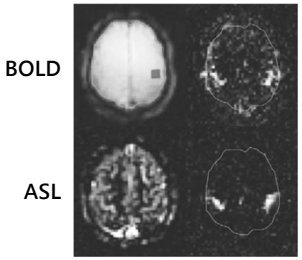


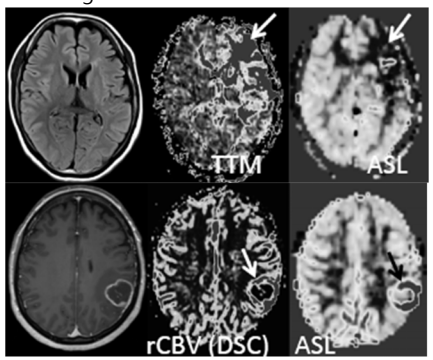
Adapted from Jean-Yves Gauvrit

Applications

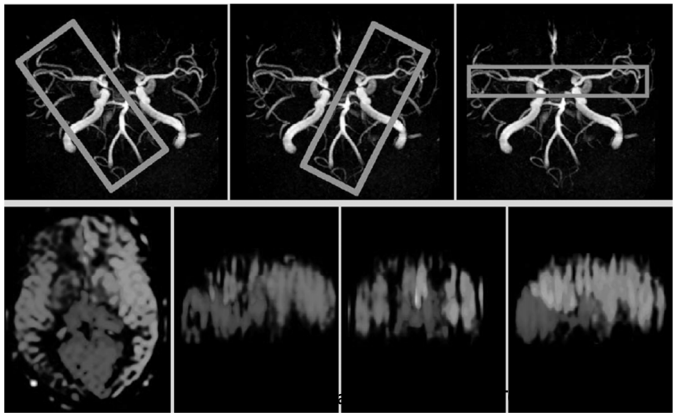
- Tumor characterization
- Neurovascular disease
- Brain functional activation

- Wolf et al. JMRI 2005
- Wang et al. Stroke 2012





Selective excitation and vascular territories



THE END

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