Arterial Spin Labeling (ASL) for Brain Imaging

Consensus and Recommendations by the Experts

ASL Papers

Recommended implementation of arterial spin-labeled perfusion MRI for clinical applications: A consensus of the ISMRM perfusion study group and the European consortium for ASL in dementia.


An introduction to ASL labeling techniques.

Wong EC. J Magn Reson Imaging. 2014 Jul;40(1)

Schematic Diagram of ASL

Recommendations

1. Hardware considerations;
2. Labeling approaches;
3. Time delay between labeling and imaging;
4. Background suppression;
5. Readout approaches;
6. Post-processing methods;
7. ASL in the clinical setting.

Hardware considerations

- 3T
  - Higher SNR
  - Longer T1 (longer life time of tracer)
- Multichannel head coil
  - Higher SNR
  - Parallel imaging to reduce echo time

Labeling approaches

- Continuous labeling
  Over a long period of 1 – 3 second as blood flow through a labeling plane. (Flow driven adiabatic inversion)
  - CASL: a single long labeling pulse
  - PCASL: a series (>1000) short (~1us) pulses
- Pulsed labeling
  A single or a few short pulses over 10-20 ms
- Velocity selective labeling
**Advantages of PCASL over CASL**

- Reduced subtraction error due to MT effect
  - Larger gradient
  - Increased frequency offset to brain tissue
  - Less saturation from magnetization transfer
  - Reduced subtraction error between control and labeling
- Compatible with existing RF amplifier

**Labeling RF train and duration (τ)**

- Higher labeling efficiency with longer duration
- Diminishing returns for label durations much longer than the T1 of blood, $1-e^{(-t/T1)}$
- Longer durations increase TR, and thereby decrease the number of averages obtained per unit time.
- Just below the inferior border of the cerebellum to ensure labeling of the posterior cerebral circulation.
- Avoid labeling in regions of strong susceptibility artifacts (inefficient labeling if off-resonance)
Post Labeling Delay (PLD)

- For CBF quantification using PCASL, ideally, PLD should be just longer than the longest ATT.
- Areas of low ASL signal may reflect some combination of low CBF and unusually long ATT.
- Multi-TI/PLD method is needed for the estimation of ATT or the most precise quantitation of CBF.

Recommended Labeling Parameters

- PCASL: average labeling gradient 1 mT/m
- PCASL: slice-selective labeling gradient 10 mT/m
- PCASL: average B1 1.5 mT
- PCASL labeling duration 1800 ms
- PCASL PLD: neonates 2000 ms
- PCASL PLD: children 1500 ms
- PCASL PLD: healthy subjects <70 y 1800 ms
- PCASL PLD: healthy subjects >70 y 2000 ms
- PCASL PLD: adult clinical patients 2000 ms
- PASL TI 1.800 ms
- PASL TI: Use PCASL PLD
- (from above)
- PASL labeling slab thickness 15–20 cm

Background Suppression (BS)

- In gray matter, perfusion replaces 1% of the brain water with in-flowing blood water every second.
- The difference between label and control images is typically <1% of the relaxed brain signal.
- Subject motion produces signal fluctuations (noise and/or artifacts) that are proportional to the signal intensity in the un-subtracted images.
- There is a trade-off in the number of inversion pulses used for BS.
- BS only nulls the magnetization of static tissue at one point in time. For a single excitation per TR, such as 3D readout, BS can be highly effective.
Readout Approaches

- 2D single-shot (past)
  - Less sensitive to motion between excitations.
- 3D segmented (present)
  - High efficiency
  - FSE (T2* insensitivity) + EPI (acquisition efficiency)
  - 3D RARE stack of spirals (blur) or 3D GRASE (distortion)
- 3D single-shot (future)

2D vs 3D readout

Vascular Crushing Gradients

- Bipolar gradients as in PC-MRA
- H/F direction with VENC=4cm/s
- Prolongs TE -> reduction in SNR + T2 (or T2*) weighting
- User selective option (depending on the application)
  - Bright vessel indicates long ATT, an useful info.
  - Use PLD > ATT or multiple PLD

CBF Quantification Assumptions

- The entire labeled bolus is delivered to the target tissue (PLD > ATT)
- Rapid exchange and no outflow of labeled blood/water
- T1 of labelled spin = T1 of blood (not influenced by tissue)

CBF Formula

\[
CBF = \frac{6000 \cdot \lambda \cdot (S_{\text{control}} - S_{\text{label}}) \cdot \frac{\text{PD}}{\text{blood}}}{2 \cdot \alpha \cdot T_{1,\text{blood}} \cdot S_{\text{PD}} \cdot (1+\frac{\lambda_{\text{water}}}{T_{1,\text{water}}})} \quad [\text{ml}/100 \text{ g/min}]
\]

\( \lambda \) (blood–brain partition coefficient or tissue water content) = 0.9 mL/g (74)
\( T_{1,\text{blood}} = 1650 \text{ ms at 3.0T} \), \( T_{1,\text{blood}} = 1350 \text{ ms at 1.5T} \) (75)
\( \alpha \) (labeling efficiency) for PCASL = 0.85 (17)
The factor of 6000 converts the units from mL/g/s to mL/(100 g)/min
- SI_{PD} (Proton Density weighted signal) acquired with
  - Long TR (>5s) or corrected with tissue T1
  - No labeling or BS
  - Motion corrected and smoothed
ASL Pitfalls

- For PCASL scans, look for areas of low labeling efficiency.
- Note the overall gray matter CBF value (Should be 40-100 mL/min/100 mL)
- Check for motion artifacts (ASL signal outside of brain)
- Look for intravascular artifacts.

THANK YOU