Extra-neurite Perfusion Measurement with Combined Arterial Spin Labeling and Diffusion Weighted MRI

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Introduction:

Arterial Spin Labeling (ASL) is an MRI method that uses magnetically labeled endogenous water as a tracer for measuring cerebral perfusion in vivo[1]. The arterial water that is usually 'labeled' at a plane positioned at the base of the brain, perpendicular to the carotids. A post-labeling delay (PLD) is introduced prior to acquisition to allow labeled water to cross the vasculature and perfuse into the tissue[1]. Because of signal decay due to T1 relaxation, fast acquisition schemes are employed to ensure optimal SNR. Consequently, the spatial resolution of ASL is relatively low (~ 3 x 3 x 6 mm^3). As such, the measured blood flow from a given voxel reflects a mixture of signals from gray matter (GM), white matter (WM), and CSF, a phenomenon known as partial voluming (PV)[2]. To correct for the confounding effects of PV in ASL imaging, an algorithm (PVC) has been developed and already used by several studies[2,3]. The algorithm is based on GM and WM volume data obtained from the segmentation of the T1w image[2], and makes no further distinction between different compartments within the same tissue type. Here, we investigated the potential of PVC ASL to map blood perfusion in the extra-neurite compartment (e.g., soma, glial cells[4]) and the intra-neurite (comprised of axons and axon terminals[4]) within the same tissue, independently. We applied the PVC algorithm using compartmental data from a diffusion weighted imaging (DWI) model, referred to as NODDI[4]. The underlying hypothesis was that the blood flow in the extra- and intra-neurite compartments would vary with the PLD; a short PLD acquisition would increase the flow in the extra-neurite compartment compared to the long PLD for which there should be an increased flow in the intra-neurite compartment instead.

Methods:

Theory

At any given voxel, the blood flow (f_T) is given as:

$f_T=VF_{In}\bullet f_{In}+VF_{En}\bullet f_{En}+VF_{Iso}\bullet f_{Is}$

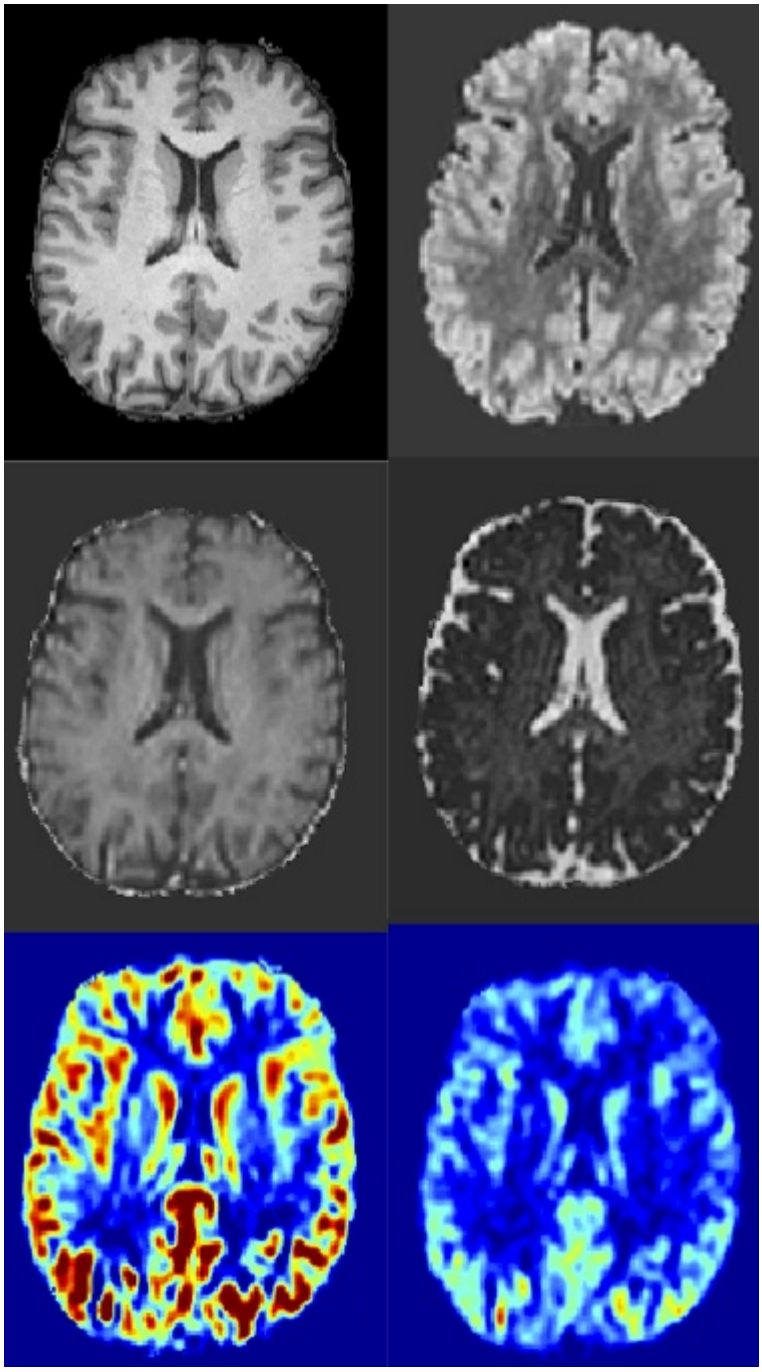
where, VF_{In}, VF_{En}, VF_{Iso} represent respectively: the intra-neurite, extra-neurite, and non-tissue compartments obtained from NODDI[4]. By assuming that for each compartment blood flow is constant over a 'kernel', the equation can be re-written in vectorial form to reflect the flow at the voxel in the center of the kernel[2], from which then each compartmental flow can be computed using linear regression as detailed in Asllani et al.[2].

MRI protocol & image analysis

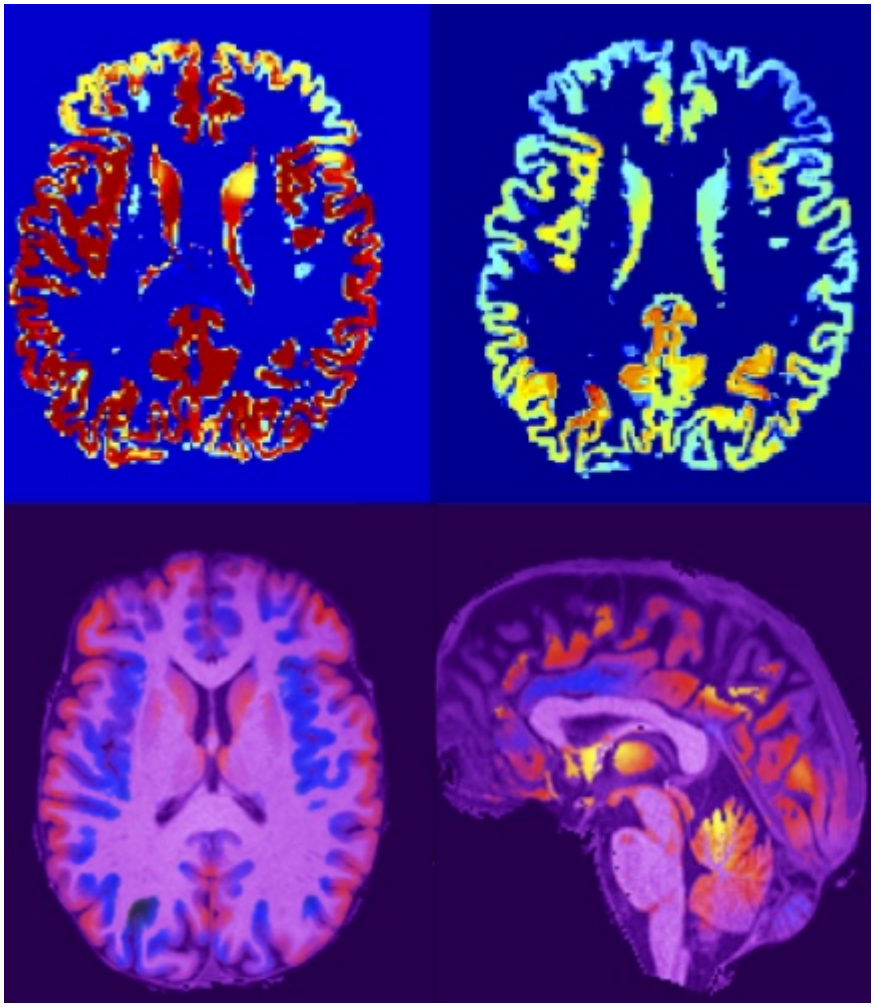
T1w (MPRAGE), NODDI, and ASL MRI images were obtained on 4 healthy participants (mean age = 44.5 ± 7.4 y, 2 men) a Siemens 3T system. To test the hypothesis that a shorter PLD would increase the signal in the extra-neurite GM compartment, ASL was acquired with a short (200ms) and long PLD (1800ms). Only results from voxels with GM content > 80% are presented.

Results:

Fig.1 shows the raw images that were used by the PVC algorithm to extract the flow from each compartment within the GM. For the long-PLD acquisition, average CBF in the extra- and intra-neurite compartments was 76 ± 10 mL/100g*min and 59 ± 8 mL/100g*min, respectively. As hypothesized, for the short-PLD, the CBF signal was contained primarily in the extra-neurite department (118 ± 17 mL/100g*min) with the intra-neurite compartment flow being essentially zero (-0.9 ± 0.6 mL/100g*min). Results from one participant are shown in Fig.2.



·Fig.1: 'Raw' NODDI and ASL images used by the PVC algorithm from one subject. Top row: MPRAGE and VFIn images; middle row: VFEn and VFISO; bottom row: CBF for short PLD (left) and long PLD (right).



·Fig.2: Top: Extra-neurite GM CBF from short (left) & long (right) PLD acquisitions. Bottom: axial and sagittal views of Intra-neurite CBF for long PLD with areas in blue indicating ~zero signal.

Conclusions:

We combined NODDI with PVC ASL MRI to distinguish between blood flow in the extra- and intra-neurite compartments within GM. While these initial results look promising, more work is needed to test the sensitivity of this method and its feasibility for clinical applications. For example, a larger PLD range is needed to test whether the method can be used to detect inter-neurite subcortical flow. If successful, this method could prove invaluable in mapping blood flow with high spatial specificity.

Imaging Methods:

Diffusion MRI
Multi-Modal Imaging
Non-BOLD fMRI [2]

Physiology, Metabolism and Neurotransmission :

Cerebral Metabolism and Hemodynamics
Neurophysiology of Imaging Signals [1]

Keywords:

Cerebral Blood Flow
Data analysis
fMRI CONTRAST MECHANISMS
MRI

[1|2]Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Other

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Yes

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

Functional MRI
Structural MRI
Diffusion MRI

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

SPM

Provide references using author date format

1 D. C. Alsop, et al., Magnetic Resonance in Medicine 73(1), 2015; 2 I. Asllani, et al., Magnetic Resonance in Medicin 60(6), 2008; 3 A. Borogovac and I. Asllani, Internationa Journal of Biomedical Imaging., 2012; 4 H. Zhang, et al., NeuroImage 61, 2012