# Reinvestigation of perfusion measurement in cerebral white matter using pseudocontinuous arterial spin labeling MRI

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## Introduction

The feasibility of arterial spin labeling (ASL) MRI in cerebral perfusion measurement has been recognized in gray matter, but remains pending in white matter, mainly due to the tissue's low flow rate and long transit time. Based on experiments and simulations, van Gelderen and coworkers recently showed that white matter perfusion cannot be reliably measured with pulsed ASL[1]. By taking advantage of the higher signal-to-noise ratio (SNR) obtainable with pseudocontinuous ASL (PCASL[3]), van Osch et al [2] demonstrated the possibility of perfusion measurement in white matter, using a relatively long labeling duration in conjunction with a long post-labeling delay with no optimization. In this study, we tried to optimize these parameters experimentally and numerically, based on a spatial resolution (1.56x1.56x5 $mm^3$) finer than commonly used (3.4x3.4x5 $mm^3$) to avoid partial volume effect.

## Materials and Methods

MR Experiment. The Institutional Research Ethics Committee approved this study. Ten healthy volunteers (F/M =5/5, 22-30 y/o) were included. Written informed consent was obtained from each of them beforehand. All MR imaging was performed on a 3T whole body scanner (Tim Trio, Siemens) using the body coil to transmit RF pulses and a 12-channel phased-array head coil to receive signals. After anatomic imaging, a series of PCASL scans were performed with varied labeling duration ($\tau$ = 1000, 1500, 2000, and 2500 ms) and post-labeling delay (PLD = 1000, 1400, 1800, and 2200 ms): TR/TE = 5500/18 ms, matrix = 128x128, GRAPPA acceleration factor = 2, 12 axial slices acquired in an ascending order (inter-slice gap = 1 mm in space and 60 ms in time), 40 pairs of tag and control measurements. After motion correction, ASL images were corrected for spatially varying coil sensitivity and then pair-wise subtracted to generate perfusion-weighted images. For each $\tau$ and PLD, perfusion-weighted images were averaged (dM) and converted to quantitative CBF maps. The anatomic images were segmented into gray matter, white matter, and CSF, and then co-registered to the mean motion-corrected ASL images. Signal intensity and perfusion were analyzed within binary masks (probability threshold = 0.95 for gray matter and 0.99 for white matter). The mean and standard deviation of ghost-free background were computed (X and SD, respectively). Detectable voxels were defined as those with signal intensity larger than X+SD. The mean intensity of dM was plotted against $\tau$ and PLD, respectively, to determine the optimal $\tau$ and PLD, based on which, perfusion-weighted SNR ($SNR_{dM}$) was examined on a subject-wise basis as well as on the group level. For group analysis, all datasets were pooled to create templates for both anatomic and echo-planar images. Each subject's images were normalized to the templates.

Computer simulation. Based on the framework described by van Gelderen et al [1], the SNR of perfusion-weighted images (dM) can be related to the SNR of fully relaxed longitudinal magnetization of arterial blood $M_{0b}$:

$$SNR_{dM} = 2 \cdot \alpha \cdot f \cdot g(t, \tau, \delta, T_{ex}, T_{1b}, T_{1t}) \cdot \sqrt{0.5} \cdot \sqrt{N} \cdot SNR_{M_{0b}}$$

where $\alpha$ and $f$ are labeling efficiency and blood flow, respectively. Function $g$ [4] accounts for the temporal evolution dictated by $\tau$, transit delay ($\delta$), exchange time ($T_{ex}$), $T_1$ of tissue ($T_{1t}$) and arterial blood ($T_{1b}$).The square root of 0.5 is the penalty of using pair-wise subtraction to generate dM images, N is the number of dM images averaged. $SNR_{M0b}$, was estimated from the SNR of ventricular CSF.

## Results and Discussion

As shown in Fig 1 (PLD = 1800 ms), a $\tau$ longer than 2000 provides little benefit in terms of SNR. The transit delay ($\delta$) of white matter is found to be around 1500 ms (Fig not shown), in agreement with literature values. Fig 2 ($\tau$ = 1500 ms) shows that more than half of white matter is detectable with our imaging setting. Shown in Fig 3 are the cohort maps of $SNR_{dM}$. In Fig 4, $SNR_{dM}$ is computed for various combinations of $\tau$, PLD, and $\delta$, suggesting that with $\tau$ = 2000 ms, perfusion cannot be measured when $\delta$ is longer than 2600 ms. It is for sure that PLD should be at least as long as $\delta$ to avoid intravascular signal, and at the same time, as short as possible to keep SNR from decrease.

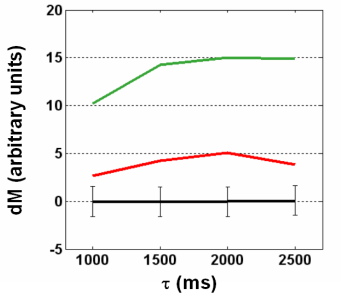


**Fig 1.** Data from one subject. Green/red = gray/white matter. Black = background signal (error bars = standard deviation).

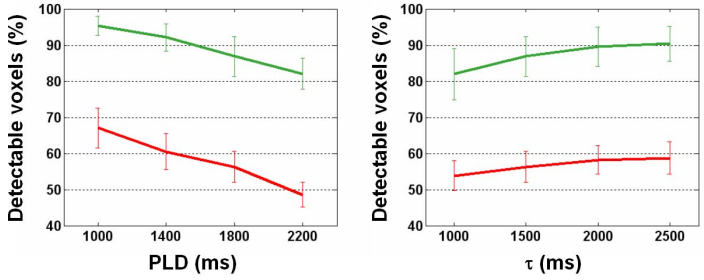


**Fig 2.** Error bars indicate the standard deviation of 10 subjects. Green/red = gray/white matter.

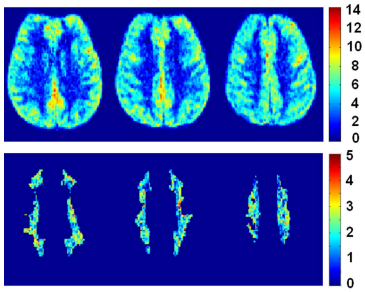

**Fig 3.** Maps of perfusion-weighted signal to noise ratio ($SNR_{dM}$) averaged across 10 subjects.

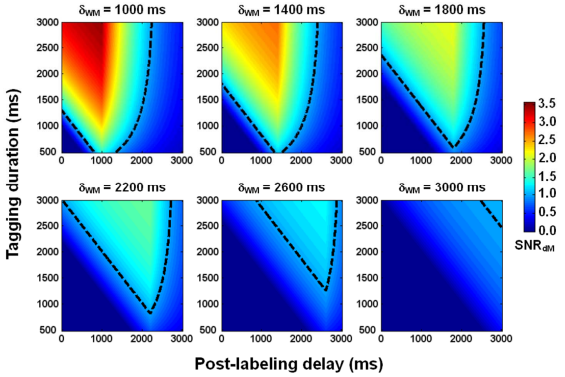


**Fig 4.** The dashed lines indicate the contours where $SNR_{dM}$ = 1. $\alpha$ = 0.85, f = 60/20 ml/100ml/min for gray/white matter. $T_{ex}$ = 100 ms.

## Conclusion

By combining the experimental and numerical data, we have shown that cerebral perfusion can be measured in the majority of white matter and that the optimal value is 2000 ms for $\tau$ and 1500-1800 ms for PLD.

**References** 1. van Gelderen P, et al, MRM 2008;59:788.
2. van Osch MJ, et al, MRM 2009;62:165. 3. Garcia DM, et al, ISMRM 2005;13:37. 4. Buxton RB, et al, MRM 1998;40:383.