The Effect of Arterial Blood Velocity Variation over the Cardiac Cycle on the Temporal SNR of the CASL Perfusion Time Series

M. A. Fernandez-Seara[1], J. Wang[1], J. A. Detre[1]

[1]Center for Functional Neuroimaging, University of Pennsylvania Medical Center, Philadelphia, PA, United States

Introduction: Continuous arterial spin labeling (CASL) techniques use flow driven adiabatic inversion of blood water spins to image perfusion. The inversion efficiency is determined by the relationship of the blood velocity as it crosses the inversion plane to the parameters (B_1, G) of the labeling pulse. Thus arterial blood velocity changes over the cardiac cycle can have a significant effect on the degree of inversion (1). For resting perfusion measurements, a large number of difference images (tag - control) are typically averaged, including difference images obtained during all phases of the cardiac cycle, which can mitigate the effects of efficiency variability. However, for time series studies such as functional imaging, the efficiency variability should be minimized. For this type of experiment, TR may also be reduced to increase temporal resolution. Reducing TR requires a short labeling time, which in turn is likely to increase the inversion efficiency variability and thus decrease the temporal SNR (tSNR). Here, we have performed simulations and experiments to study the effect of TR and labeling time on the tSNR of CASL perfusion series.

Materials and Methods: Simulations were performed to calculate the average inversion efficiency for a given labeling time, taking into account blood velocity variations during the cardiac cycle, approximated with the profile shown in Fig. 1. Simulations were based on the numerical integration of the Bloch equations, using the approach in (2). The cardiac cycle was divided into 10 phases. For every measurement, the cardiac phase at the beginning of the labeling was determined considering the cardiac cycle duration and TR. The velocity profile of the blood crossing the inversion plane during labeling was then obtained (Fig. 2a). For a given time point, blood velocity was assumed constant in the vessel cross-section. For each measurement, the position of the blood spins was computed as $z(t) = \int v(t)dt$ and the offset frequency as $w(t) = 2\pi\gamma\ Gz(t)$, which does not change linearly with time (as opposed to the case of constant velocity). The time-varying offset frequency and the RF amplitude were used to compute the efficiency of the inversion (Fig. 2b). The volume of blood inverted was calculated as the product of the velocity at the inversion plane times the area of the vessel (considered constant = 1cm^2). The average inversion efficiency was then computed as the efficiency of every cardiac phase weighed by the volume of blood inverted, following Eq. [1]:

$$eff = \frac{\sum_i \varepsilon(i) vol(i)}{\sum_i vol(i)} \qquad [1]$$

where the summation extends to all the cardiac phases that cross the inversion plane during the labeling time. This calculation was repeated for 50 measurements. Subsequently the average and standard deviation of the efficiency values were calculated for a range of labeling times. Other simulation parameters: B_1=23 mG, G=0.16 G/cm, blood T_1 / T_2 =1.5 sec and 0.1 sec, TR = 4 sec, cardiac cycle duration = 0.917 sec, systole = 0.15 sec, diastole = 0.767 sec.

Experiments were carried out using a 3T Siemens Trio scanner. A head coil (Bruker) was used for transmission and reception. Axial brain images of 3 volunteers were acquired, following written informed consent, with a CASL 2D EPI sequence with amplitude modulated control (3), with G=0.16 G/cm, B_1=22.5 mG and frequency modulation for the control RF=100Hz. Imaging parameters: resolution=3.75x3.75x6 mm^3, FOV=240x240 mm^2, 8 slices, matrix=64x64, BW=3004 Hz/pixel, post-labeling delay=0.8 sec. Three acquisitions were performed varying the labeling pulse duration and adjusting TR accordingly. The number of measurements was varied to keep the scan time constant (Table 1). The images were motion-corrected using SPM2 and the difference images (tag-control) were computed. Then the tSNR of the global difference signal was calculated.

Results and Discussion: The simulation results show that changes in the velocity of the blood as it crosses the inversion plane over the course of the cardiac cycle have a significant effect on the inversion efficiency (Fig. 2b). However, the efficiency variability from measurement to measurement decreases as the labeling period increases and covers more than one cardiac cycle (Fig. 2c). As a result, decreasing the labeling time to a period shorter than one cardiac cycle has a tSNR penalty even though the TR can be reduced and the number of measurements increased for a given scan time, as demonstrated by the experimental data (Table 1). In the case of rapid acquisition, cardiac gating should be considered to reduce measurement to measurement variability. The simulation performed in this work could be improved by considering a realistic distribution of velocities in the cross-sectional area of the vessel. In addition, the efficiency of the labeling in the imaging plane should be computed, because protons moving with higher velocity will arrive at the imaging plane faster, allowing less time for T_1 relaxation of the blood, as mentioned in (1).

Table 1: Acquisition parameters and tSNR (normalized to the tSNR of the last scan for every subject)

Labeling time [sec]	TR [sec]	Number of measurements	Scan time [sec]	tSNR
0.8	2	240	480	0.59±0.18
1.6	3	160	480	0.85±0.04
2.0	4	120	480	1

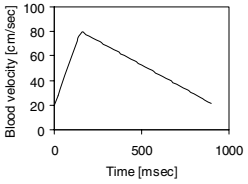

Fig. 1: Simulated velocity profile during the cardiac cycle.

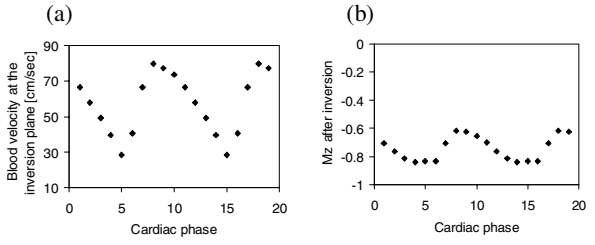

Fig. 2: (a) Velocity of the blood spins as they cross the inversion plane as a function of cardiac phase. (b) Efficiency of the inversion as a function of cardiac phase. (c) Standard deviation of the efficiency calculated from a group of 50 simulated measurements.

Conclusions: Variations of blood velocity over the cardiac cycle have an effect on the inversion efficiency variability in CASL perfusion measurements. This effect can be reduced by increasing the duration of the labeling pulse to cover two or more cardiac cycles. In the case of shorter labeling times, cardiac gating should be considered. These results also have implications for pulsed ASL experiments.

Bibliography: 1. Utting et al. MRM 49:398-401 (2003). 2. Maccotta et al. NMR in Biomedicine 10:216-221 (1997). 3. Wang et al. Radiology 235:218-228 (2005).
Acknowledgments: NS045839, DA015149, BCS-0224007, P41-RR02305.