Toward Quantitative Whole Brain Pulsed Arterial Spin Labeling: Estimation of Transit Time with Cardiac Gating at 3T

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Introduction

Pulsed arterial spin labeling (PASL) experiments rely on available physical space outside imaging volume to create tagged blood for perfusion measurements. In contrary to the use of head RF coils, the use of high sensitivity receive-only phased array coils and large body coil excitation provides optimal configuration for PASL experiments with high SNR for signal acquisition and large tagging volume. With the availability of larger tagging size (>10cm), whole brain coverage may be achieved. Although previously it was shown theoretically (1) that in quantitative PASL a longer temporal tag size does not improve SNR efficiency due to TR penalty for longer TI1 time. However, with normal blood velocity (30~80 cm/s) in internal carotid arteries, a tag size of 15cm is cleared in about 200~500ms. The temporal width of the tag is likely to increase sublinearly with the physical tagging size but the tagged blood volume is likely to increase superlinearly. In addition, longer T1 at 3T compared to 1.5T requires an increase of the optimal tag width from 700ms to 920ms in order to operate similarly at about 3% off the maximal SNR efficiency. Moreover, the penalty for tagged blood to clear the tagging area is negligible due to fast flowing velocity. The penalty in increased transit time for tagging below the brain with whole brain coverage is also smaller than expected because of fast flowing spins in the increased gap between tagging area and imaging slices. Therefore the knowledge of transit time with tagging below the brain is essential in optimizing quantitative PASL for whole brain coverage. In this study PASL for the whole brain at 3T was considered and the transit time to the whole brain was estimated using larger tag size with cardiac gating.

Methods

PASL was performed with PICORE (2) tagging scheme using BASSI (3) adiabatic pulses for improved inversion profiles for larger tag size as well as subtraction errors in imaging slices. The use of two pre-saturation pulses preceding the tagging pulses further improved subtraction errors and allowed variable TR with cardiac gating. A pulse oximeter was used for cardiac gating with a 3T scanner. To assess the effects of cardiac gating, two PASL runs with 30 pairs of tag and control images at TI/TR=1400/3000ms were performed with and without cardiac gating. For transit time estimation, TI was varied from 400ms to 2400ms in a step of 200ms with a 15cm tag. The gap between the imaging volume and the tagging area was kept at 1cm to avoid tagging in the circle of Willis since the increase of transit time due to the gap is expected to be minimal. An imaging volume of 10.3cm was achieved with 13 axial slices (7mm thick with 1mm gap) and a total of 40 pairs of GE-EPI images were acquired for each TI with bipolar diffusion gradients of b=1mm/s2 to provide better transit time estimation to the brain parenchyma. The acquisition time for each slice is 58.8ms with TE/TR=28/3300ms. The pair-wise subtracted and averaged perfusion images at each TI were fitted to a kinetic model (2) to estimate the transit time on a voxel-wise basis. To assess the effectiveness of TI1 saturation, a series of Q2TIPS (4) saturation was applied with TI1 from 550ms to 1150ms in a step of 150ms and TI1s/TI2=1200/1550ms. In addition, T1 maps were derived from TI-stepping inversion recovery EPI images with 16 TI values varying logarithmically with a TR of 6 sec. Gray matter (GM) ROIs were selected based on the T1 maps.

Results

The ratios of the mean perfusion and temporal standard deviation of the subtracted image pairs with and without gating in GM ROIs across 13 slices were 1.04±0.12 and 0.83±0.15, respectively. It is equivalent to approximately 10% improvement in temporal SNR with cardiac gating. Fig.1 shows the estimated transit time (top) with the colorbar on the right representing 0-2000ms and the fitted perfusion (bottom) images. Only voxels with high perfusion signal are shown. In general, transit times are longer toward the parietal and occipital lobes. The histogram from voxels in Fig.1 is shown in Fig.2 (left) with a 11ms smoothing window. The mean and standard deviation for each slice as a distance from the distal edge of the tagging area are shown on the right in Fig.2. The mean transit times increase progressively as further away from the tagging area with the last slice at around 1400ms. Due to the application of diffusion weighting gradients, the estimated transit time may be longer than needed for PASL experiments. The 2D image acquisition scheme from bottom to top slices provides tradeoff among SNR, slice thickness, and perfusion quantification as long as the traveling speeds of the slice acquisition is fast than the fastest flowing spins in the slice. Fig.3 shows the calculated perfusion obtained with Q2TIPS at different TI1 times averaged from all slices in GM ROIs. Due to fast flowing blood in the tagging area, the TI1 saturation is no longer very effective.

Discussion

With tagging below the brain in large arteries, the consideration and conclusion from earlier studies with tagging in the brain are rather different. The tagging efficiency is expected to be very good even at high flow velocity (1); however, the transit time is likely to fluctuate if cardiac gating is not used as shown in the differences in temporal variation with and without gating. Cardiac gating provides unique improvement in reducing variation due to pulsatility in PASL and may not be beneficial for continuous ASL. Ideally, the tagging should be applied during low velocity at the end of the diastolic phase right before the systolic phase in the carotids to minimize the transit time. The application of TI1 saturation is no longer effective and even with effective saturation the TI1 time may not correspond to the temporal size of the tag and may depend on the cardiac phases. Since only large vessels are involved in the tagging, the creation of a well-defined width bolus may be simply achieved with the size control of the tagging pulses. The signal should be quantitative as long as the acquisition time is long enough to compensate for transit time plus the temporal width of the tag. At even higher field strength, the optimal tag width is even longer but the availability of a large tagging coil is questionable.

References

1.Wong et al., *MRM* 40: 348 (1998). 2. Wong et al., *MRM* 39: 702 (1998). 3. Warnking et al., *MRM* 52: 1190 (2005). 4. Luh et al., *MRM* 41: 1246 (1999).

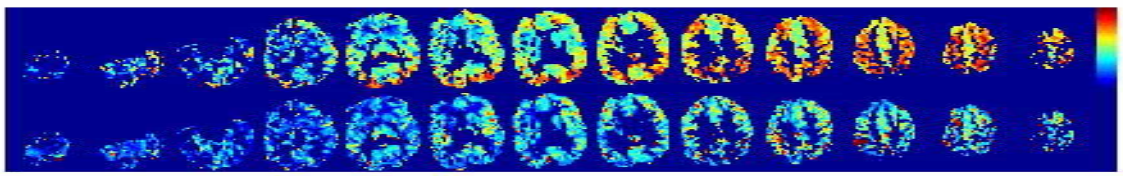
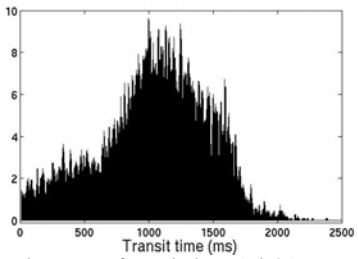


Fig. 1. Transit time maps (top row) and perfusion (bottom row) images. The colorbar on the right representing 0-2000ms for transit time maps.



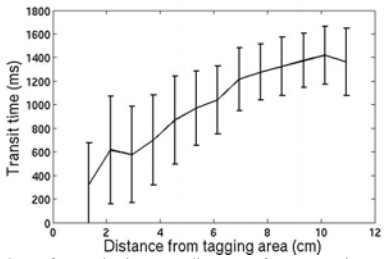


Fig. 2. (Left) Histogram of transit time; (Right) Mean and SD of transit time as distance from tagging area.

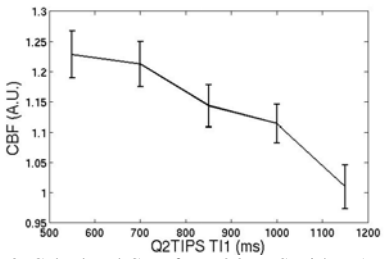


Fig. 3. Calculated CBF from Q2TIPS with TI1 stepping.