Accuracy of Pulsed Arterial Spin Labeling in the Brain: Tag Width and Timing Effects

D. S. Bolar[1], T. Benner[1], J. B. Mandeville[1], A. G. Sorensen[1], R. D. Hoge[1]

[1]Athinoula A. Martinos Center for Biomedical Imaging, MGH-HMS-MIT, Charlestown, MA, United States

Introduction

With the availability of whole-body excitation coils on high-field MR systems, it has become possible to use wider tagging bands in pulsed arterial spin labeling (ASL) experiments. Previously, tagging regions were limited to the volume covered by the head coil and typically did not exceed 10 cm. In this study, we examined the impact of tag thickness on bolus delivery dynamics and flow sensitivity, in whole-body MR systems. Observed tag delivery times (τ) were compared to suggested literature values for QUIPSS2 saturation delay times. Representative perfusion maps and inflow curves acquired at varying tag thicknesses are presented, with the standard kinetic model for quantitative ASL perfusion imaging applied (1). Perfusion sensitivity as a function of tag thickness was assessed.

We also investigated the bolus delivery dynamics during a global flow perturbation (hypercapnia) to assess the vulnerability of pulsed tagging schemes to errors caused by shifts in bolus delivery timing. Representative inflow curves of normocapnia and hypercapnia are presented, with the standard kinetic model applied.

Methods

Pulsed ASL experiments using the PICORE tagging scheme were performed on a Siemens 3T Trio whole-body scanner, equipped with an 8-channel phased-array head-imaging coil. Adiabatic inversion was done using a c-FOCI radiofrequency pulse via body coil transmission. The imaging sequence was modified to cycle through a range of inversion times (TIs) in a single scan; this "TI stepping" allowed characterization of the entire bolus inflow curve. The imaging parameters were TI = 50 ms to 1550 ms, in increments of either 100 ms or 150 ms; TR = 3 sec; FOV = 225 mm; 64x64 matrix; 330 - 480 measurements; slice thickness = 5mm; interslice gap = 2.5 mm; and scan time = 16 – 23 min. Six axial slices were positioned parallel to the ACPC line, such that the inferior-most slice intersected the lateral ventricles. To investigate effects of variable tag thickness, three scans were performed using inversion bands of 5 cm, 10 cm, and 20 cm, with a 10 mm gap between inversion and imaging regions. Three healthy human volunteers were imaged. To investigate effects of a global flow perturbation, two scans were performed using a 10 cm tag with a 20 mm gap. Bipolar crusher gradients were added to the pulse sequence to suppress vascular contribution. In the first scan the subject breathed room air; in the second scan the subject breathed an air mixture composed of 7% carbon dioxide. Two healthy humans were imaged.

Multiple-subtraction analysis was consistent for all experiments. Perfusion-weighted maps were generated by subtracting tag images from control images and correcting with the M_{OB} magnetization calibration constant (2). Maps at a single TI were averaged together to produce a single map for each TI. Regions of interest were drawn in five gray matter gyri; signal intensities from voxels within an ROI were averaged and plotted versus TI. This inflow plot was fit with the standard kinetic model (SKM) for quantitative ASL perfusion imaging and delivery parameters were reported.

Results and Discussion

Figure 1 shows three representative perfusion maps at TI = 1400 ms for tagging widths of 5 cm, 10 cm, and 20 cm from subject 1. Figure 2 shows representative inflow curves at each tag width, from a single gray matter ROI. Also displayed are the SKM fit curves and relevant parameters. Prior ASL literature has suggested using TI1 and TI2 delay times of 700 ms and 1400 ms, respectively, with a 10 cm tag width, to remain quantitative for a single tag-pair QUIPSS2 acquisition (2,3). The data presented here, however, suggest that a 10 cm tagging band is insufficient when using a TI1 of 700 ms, since the delivery time can be lower than 700 ms. Under such circumstances, QUIPSS2 saturation would not temporally define the bolus, as saturation pulses would be applied after the trailing edge of the tag arrives at the imaging slab. Such a phenomenon will cause an underestimation of flow. Table 1 summarizes bolus delivery times, along with the % error in flow calculation the described QUIPSS2 experiment would cause. Furthermore, these experiments were performed at baseline conditions; increases in CBF (as in task-based activation or hypercapnia induction, for example) will lead to much more severe errors, as shown below. Use of a 20 cm tag avoids this error in flow calculation, since delivery times are much longer than 700 ms. Additionally, use of a 20 cm tag affords greater sensitivity to the perfusion signal; the associated ROI SNR is 1.6 times that of the ROI associated with the 10 cm tag, and 4.45 times that of the ROI associated with the 5 cm tag. This increase in SNR can be exploited in a QUIPSS2 experiment by increasing TI1, since the delivery period is substantially longer.

Figure 3 shows representative normocapnia and hypercapnia inflow curves (and corresponding SKM fits) from subject 4. These data illustrate how the aforementioned phenomenon can lead to errors in detection of a global flow change, if delivery times are less than 700 ms. A QUIPSS2 single-subtraction experiment using the literature suggested parameters would give ROI values analogous to the data points at TI = 1400 ms. The percent increase calculated with these points is 17%, from normocapnia to hypercapnia; thus, a 17% increase in flow would be measured. The true flow change, however, is 66%, as given by the SKM. In other words, the QUIPSS2 experiment would cause a substantial flow underestimation, thereby altering the capacity of flow change detection.

Conclusions

QUIPSS2 allows quantitative ASL in just a single-subtraction, which is important in both research and clinical settings. For the technique to be successful, however, inversion times and tag widths must be appropriately chosen. Our results show the importance of parameter selection and suggest that the use of literature recommended inversion times and tag thicknesses can lead to error in perfusion calculation. One way to avoid perfusion error, and at the same time increase perfusion sensitivity, is to use a larger tag thickness, which is now possible on many high-field systems. An increase in perfusion sensitivity is extremely valuable in functional MRI, as changes in cerebral blood flow are often small. Furthermore, an increase in sensitivity should allow better characterization in low regions of blood flow, as in white matter tissue or tissue affected by pathology.

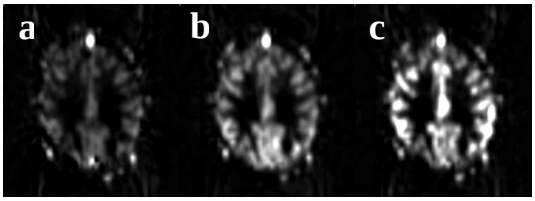

Figure 1. Representative perfusion maps at TI = 1400 ms, for tagging bands of (a) 5 cm, (b) 10 cm, and (c) 20 cm, all equally windowed. Gray matter SNR is substantially increased when larger tag widths are used, leading to higher perfusion sensitivity.

Table 1	*Avg* τ (ms)	% error in flow
Subject 1	595 ± 98	18%
Subject 2	559 ± 42	25%
Subject 3	638 ± 96	10%

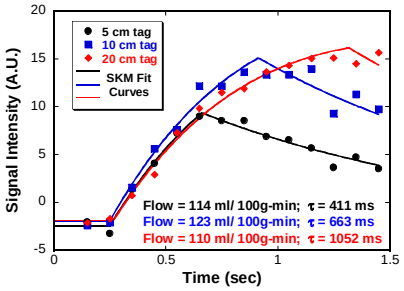

Figure 2. Representative bolus delivery profiles, with accompanying SKM fit, for tagging bands of 5 cm, 10 cm, and 20 cm. Of note are the short delivery times for the 5 cm and 10 cm tag width (< 700ms) and the increased signal at later TI points for the 20 cm band.

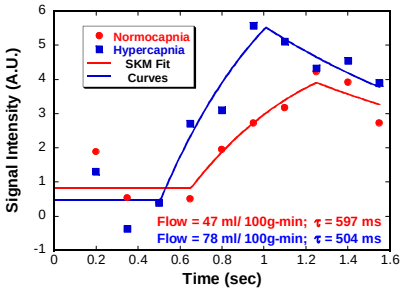

Figure 3. Representative bolus delivery profiles, with accompanying SKM fit, for normocapnia and hypercapnia. A single-subtraction analysis at long TI's would drastically underestimate the true flow change (given by the SKM fit).

References: (1) Buxton et al., MRM 40: 383-396 (1998), (2) Wong et al., MRM 39:702 (1998), (3) Wong et al., Proc ISMRM 1996, pg 13.

This work was supported in part by The National Center for Research Resources (P41RR14075) and the Mental Illness and Neuroscience Discovery (MIND) Institute