To Spoil or Not to Spoil the Tagging – Arterial Transit Time Imaging in Pulsed Arterial Spin Labeling

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Introduction Perfusion measurements based on pulsed arterial spin labeling (PASL) techniques are appealing because of the technical simplicity and relatively low levels of RF power deposition. Many of the existing PASL methods employ a saturation pulse to exogenously define the duration of the tagging bolus for quantitative perfusion measurement, as proposed in the QUIPSS technique (1). The tradeoffs of using QUIPSS type techniques are the penalty in the signal-to-noise ratio (SNR) as well as loss of transit time information which may be clinically relevant. On the other hand, PASL methods without spoiling saturation pulses have the advantage of greater SNR, but are sensitive to transit related effects leading to difficulty in perfusion quantification. We propose a combined use of conventional PASL and QUIPSS type methods (with and without the saturation pulse). By taking advantage of their complementary power, simultaneous measurements of perfusion and arterial transit time can be achieved. We provide a theoretical framework and carried out an experimental validation during steady-state imaging and functional activation on healthy subjects.

Theory The current method was developed from the FAIR technique (2), but is applicable for other PASL methods. Assuming the labeled spins stay primarily in the vasculature, the perfusion signals (ΔM and $\Delta M'$) in the FAIR and QUIPSS techniques can be expressed as Eqs. [1] and [2] respectively (3, 4), where f is CBF, T1a is the T1 of blood, A is a constant, TI is the inversion time, TI_1 is the duration between the labeling and saturation

$$\Delta M = \begin{cases} 0 & TI < \tau_a \\ 2fA\,(TI-\tau_a)\exp(-TI/T1a) & \tau_a < TI < \tau_d \\ 2fA\,(\tau_d-\tau_a)\exp(-TI/T1a) & \tau_d < TI \end{cases} \quad [1]$$

$$\Delta M' = \begin{cases} 0 & TI < \tau_a \\ 2fA\,(TI-\tau_a)\exp(-TI/T1a) & \tau_a < TI < \tau_a+TI_1 \\ 2fA\,TI_1\exp(-TI/T1a) & \tau_a+TI_1 < TI \end{cases} \quad [2]$$

pulses in QUIPSS, τ_a and τ_d are the arterial transit time and trailing time for the leading and trailing edge of the tagging bolus to reach the imaging slice, respectively. Simulation results indicate that the FAIR and QUIPSS signals start to divert at $TI > \tau_a+TI_1$ (Fig. 1), and the ratio of these two signals ($\lambda=\Delta M/\Delta M'$) provides an estimation of arterial transit time $\tau_a = TI - \lambda TI_1$ ($\tau_a+TI_1<TI<\tau_d$). At long TI values ($\tau_d<TI$), the tagging bolus width can also be calculated as $\tau_d-\tau_a=\lambda TI_1$. Quantitative perfusion values can be obtained based on Eq.[2] which are not reported in this abstract.

Methods Five healthy subjects underwent scanning on a Siemens 3.0T Trio whole-body MR system, using the product quadrature (T/R) head coil. The PASL technique consisted of interleaved slice-selective (label) and nonselective (control) inversion recovery acquisitions. For odd pair of label and control acquisitions, a saturation pulse was applied at TI_1=700ms after the inversion pulse, and to a 10cm slab inferior to the imaging slices (4). A gradient-echo EPI sequence was used for image acquisition (FOV=22cm, 64x64 matrix, TR/TE=3000/17ms, bandwidth=3kHz/pixel, slice thickness 6mm, inter-slice space 1.5mm). 12 slices were acquired from inferior to superior in a sequential order. Each PASL scan with 160 acquisitions took 8min. Three steady-state scans with TIs of 1.4, 1.7 and 2.0s were carried out on each subject. ΔM and $\Delta M'$ were obtained by averaging the odd and even number of difference PASL images respectively. Arterial transit time (τ_a) was calculated based on the above model using data acquired at TI=1.4 and 1.7s, while the tagging bolus width ($\tau_d-\tau_a$) was estimated using data acquired at TI=2.0s. Segmentation of transit time images into gray and white matter ROIs was performed using SPM. A functional scan with 240 acquisitions (TI=1.4s, 12min, 2min OFF/ON paradigm) was also performed with simultaneous visual stimulation and bilateral finger tapping as task activation. Arterial transit time was calculated for the resting and activation state respectively. The mean PASL signals and arterial transit time (τ_a) were measured in ROIs of motor and visual cortex.

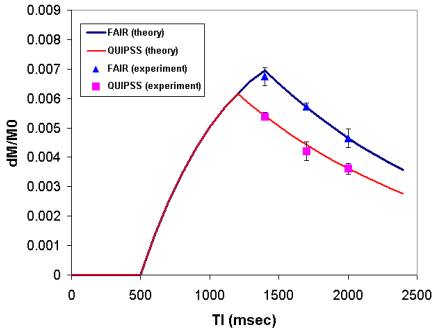

Fig. 1 Simulated and experimental FAIR and QUIPSS signals as a function of TI.

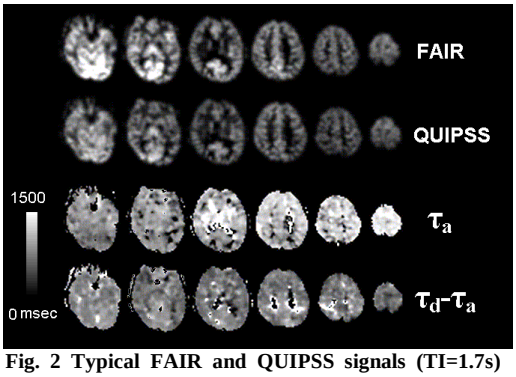

Fig. 2 Typical FAIR and QUIPSS signals (TI=1.7s) along with calculated τ_a and $\tau_d-\tau_a$ images.

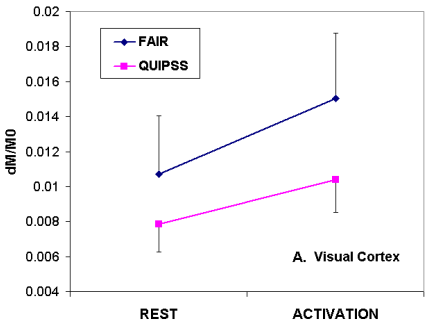

Fig. 3 Mean FAIR and QUIPSS signals during rest and activation states.

Results and Discussion The measured ratios of the FAIR and QUIPSS signals are stable (around 1.3) at three different TI values, and the PASL signal changes with TI match well with the theoretical model (Fig. 1). The mean arterial transit time (τ_a) increases from inferior to superior slices (range 500-1200ms) (Fig. 2), consistent with previous results that transit times are positively correlated with the distance between the imaging slice and tagging region (3). The mean arterial transit time is 858±63, 844±65 and 1005±89ms (average of values acquired with TI=1.4 and 1.7s) over the whole brain, gray and white matter ROIs respectively. The tagging bolus width ($\tau_d-\tau_a$), estimated using the data acquired with long TI (2s), appears to be quite homogeneous across slices and tissue types, with mean value of 927±95, 918±117 and 948±78ms in the whole brain, gray and white matter ROIs respectively. During sensorimotor stimulation, the arterial transit time decreased from 688±175 to 615±136ms in the visual cortex ($p<0.01$), and from 1039±150 to 957±182ms in the motor cortex ($p=0.12$). The mean transit time in the whole brain is not different between the resting and activation states. As displayed in Fig.3, the ratio of the FAIR and QUIPSS signals increases from 1.35 at rest to 1.44 during activation, corresponding to a 75ms reduction in arterial transit time. These results are in line with reported transit time changes during functional activation measured at various delay times (3, 5). The combination of PASL methods with and without spoiling saturation pulses provides improved image quality as well as additional information regarding arterial transit time. The approach should have clinical applications in cerebrovascular disorders.

References (1) Wong EC et al. *MRM* **39**: 702-8; 1998. (2) Kim SG et al. *MRM*. **34**: 293-301; 1995. (3) Yang Y et al. *MRM* **44**:680-5; 2000. (4) Wang J et al. *MRM* **48**: 242-254; 2002. (5) Gonzalez-At JB et al. *MRM* **43**:739-46; 2000.