Quantitative Arterial Spin Labelling (ASL) at Ultra-High Field

A. G. Gardener[1], P. A. Gowland[1], and S. T. Francis[1]

[1]Sir Peter Mansfield Magnetic Resonance Centre, University of Nottingham, Nottingham, United Kingdom

Introduction: At ultra-high field arterial spin labelling (ASL) benefits from the overall increase in signal to noise ratio and extended T_1 relaxation times of blood and tissue, leading to increased perfusion weighted (PW) signals occurring at longer delay times (TIs). However the increased B_1 and B_0 inhomogeneity at high field may also present a problem. Here the implementation of two pulsed ASL schemes, STAR (Signal Targeting with Alternating Radiofrequency) [1] and FAIR (Flow sensitive Alternating Inversion Recovery) [2] are assessed in humans at 7 T.

Theory: STAR and FAIR PASL techniques are based on the subtraction of two consecutively acquired label and non-label images. The STAR labelling scheme uses a label inversion slab (tag) applied proximal and a non-label slab (control) applied distal to the imaging slab, whilst FAIR uses a wide non-selective inversion slab for the label, and a slice-selective inversion pulse for the non-label image, both placed over the imaging slab. The difference between the non-label and label images provides a signal dependent on perfusion of the image. However B_1 and B_o inhomogeneity at 7 T can lead to imperfect inversion profiles, resulting in a small offset between label and non-label images in the absence of perfusion. This can be overcome by increasing the gap between the inversion slab and image slice, altering the width of the label/non-label, and/or applying pre-/post-saturation pulses to the imaging slices immediately before/after the inversion pulses, which can have an adverse effect on transit time. Here these factors are assessed to determine the optimal PASL sequence for use at 7 T.

Methods: Data were acquired on a 7 Tesla Philips Achieva scanner. Initial experiments were performed on a phantom to assess the inversion efficiency, α, as a function of position for various slab widths and offsets by measuring profiles through transaxial labelling slabs using sagittal SE-EPI images. For the ASL sequences, a block of five GE-EPI images with in-plane resolution of 3 x 3 mm^2, 3 mm slice thickness with 1 mm slice gap, 64 x 64 matrix and echo time of 20 ms were acquired in ascending order after each labelling scheme. STAR, using 70 mm wide label and non-label slabs, with label gaps of 10 - 25 mm between image and inversion slabs was assessed for offset signal across the multi-slice image set. For FAIR, selective slabs of 30 - 50 mm were assessed, with a 150 mm spatially-confined, non-selective labelling slab being used. Widths of all labels/non-labels were chosen to allow full refreshment of blood in the TR period. The effect of the addition of pre-/post-saturation pulses immediately before and after the inversion pulse (up to 2 of each) was assessed, along with the effect of crusher gradient area after each saturation pulse. The optimal STAR and FAIR labelling schemes were then performed on 4 healthy human adult volunteers who gave informed consent. Images were acquired at five TIs of 800, 1200, 1400, 1700 and 2000 ms with sixty ASL pairs (60 label and 60 non-label) acquired at each TI, at a repetition time (TR) of 3 s. Images were acquired both with and without velocity crushing (diffusion weighting 2.5 smm^{-1}, critical velocity 20 mms^{-1}). In addition a T_1 map and M_0 map were generated for perfusion quantification. Perfusion weighted images were formed from (non-label – label) image and subsequent quantification of perfusion performed using a model of a multi-compartment system assuming the T_1 of arterial blood to be 2.0 s (measured from blood samples at 7 T).

Results: Figure 1 shows the inversion efficiency as a function of label width for a label positioned at the isocentre of the coil and offcentre by the label width. It can be seen that the inversion efficiency is >0.98 over the central 10 cm of the label, however the sharpness of the profile is poor and varied dependent on position of pulse in the coil. This hyperbolic secant pulse had a simulated inversion profile $M_z < -0.98\ M_0$ for 86 % of slice width. This led to significant offset signal for STAR in the difference images, but not for FAIR. The effect of using pre and post- saturation pulses to suppress the static offset signal for STAR with tag gap of 25 mm was assessed in a phantom. It was found that two pre-saturation pulses resulted in a larger offset signals than a single (0.61 c.f. 0.19 %), but the application of a single pre- and post- saturation pulse with variable crushers gave the optimal reduction of the offset signal (0.15 %). The same scheme reduced the offset signal to 0.08 % in FAIR. This saturation scheme was used in subsequent subject studies, where STAR labels were set to be 70 mm wide and had to have a 25 mm label gap, whereas FAIR could use a 50 mm selective (15 mm effective label gap) and 150 mm non-selective slab, resulting in shorter transit time delays for FAIR. Table 1 shows the white matter signals for STAR and FAIR both with and without pre-/post-saturation. A large offset effect is evident in the STAR data. Figure 2 presents averaged PW images for (a) STAR and (b) FAIR (no vascular crushing). Figure 3 shows a perfusion map formed from FAIR data and Figure 4 corresponding signal change with TI in grey matter ROIs with vascular crushing applied. Perfusion maps for STAR were found to overestimate perfusion due to the static offset signal and are not shown here.

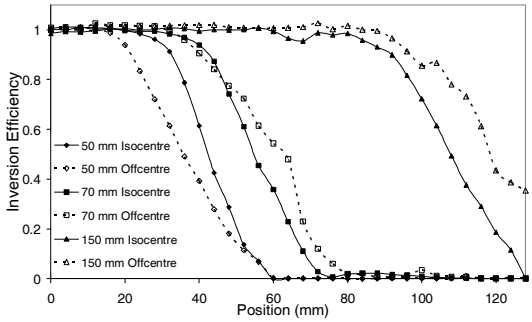

Figure 1: Label Efficiency at three widths and two positions.

	White Matter Signal (%)	
	STAR	FAIR
No pre- / postsat	1.53	0.40
1 pre- / 1 postsat	0.90	0.21

Table 1: White matter signal change for STAR and FAIR.

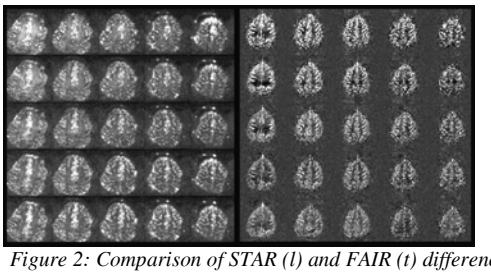

Figure 2: Comparison of STAR (l) and FAIR (t) difference images [TIs 800, 1200, 1400, 1700 and 2000 ms (rows)].

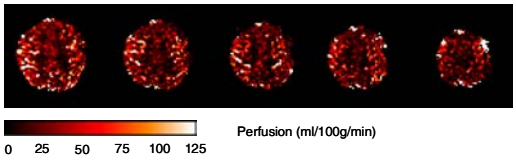

Figure 3: FAIR Perfusion map, with vascular crushing.

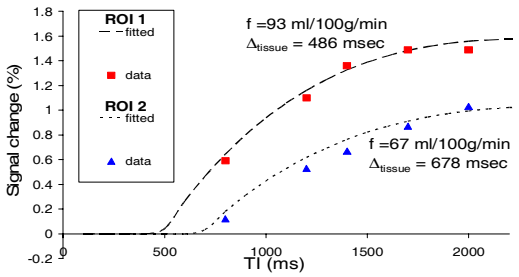

Figure 4: Measured and fitted signals for 2 grey matter ROIs.

Conclusion: At 7 T STAR was found to give a large static offset signal due to poor sharpness of the label slab profiles caused by B_1 inhomogeneity, this problem was found to be worsen away from the isocentre of the coil. The STAR static offset signal could not be fully suppressed by saturation pulses even at wider label gaps, where a longer long transit time and so reduced label efficiency results. The FAIR labelling scheme is less sensitive to offset effects since the image slab is positioned at the centre of the labels, and hence the label centres are generally positioned in the homogeneous region of the coil. With the use of pre- and post-saturation pulses good static tissue suppression could be obtained for FAIR at small label gaps. This has allowed quantitative measures of perfusion and transit time to be obtained at 7 T, with the PW signal intensity in grey matter regions of the order of 1 - 1.5 % and signal change peaking at TIs of ~ 1800 ms.

References: 1) Kim et al, MRM, 34, 293-301 (1995). 2) Edelman et al, MRM, 40, 513 (1994). 3) Pfeuffer et al, MRM, 47, 903 (2002).