Extending the Adaptive Sequential Design (ASD) Approach for Real-Time TI Optimisation in Arterial Spin Labelling

A. G. Gardener[1], S. Clare[1], and P. Jezzard[1]
[1]FMRIB, University of Oxford, Oxford, United Kingdom

Introduction and Theory: Arterial spin labelling (ASL) techniques use magnetically labelled blood as an intrinsic contrast agent to investigate cerebral blood flow (*f*). Paired control (no label) and tag (labelled) images are acquired and their difference (ΔM) gives a CBF-dependent signal. Further, obtaining images at various post-label time delays (TIs) between the application of label and acquisition allows for perfusion quantification via a suitable model [1]. This is shown in Fig. 1, with arrows showing the position of five example TIs within tag duration.

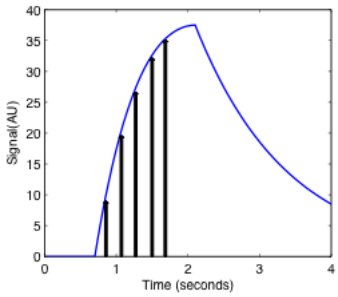

Figure 1: Model signal with five TIs.

Relatively low signal found in the ASL difference images of ~1% benefits from an optimally planned acquisition strategy. Usually this will consist of multiple repeated measures over multiple TIs, determined prior to acquisition from a literature-informed range, which make assumptions about physiological values such as arterial arrival time (inflow time, δτ) and *f*, and are mostly based on data from healthy adult subjects. It may be the case, however, that the chosen TI distribution is not optimal for a particular subject due to underlying age, gender, physiological, and/or pathological differences, such as stroke. This might not be observed until acquisition and post-processing have taken place. In order to improve *f* and δτ quantification it would be useful to have a method to optimise the TIs used whilst the subject is still inside the scanner. Recently such a technique has been shown to optimise TIs 'on-the-fly'. Adaptive Sequential Design (ASD) using an Optimal Sampling Schedule (OSS) [2] allows for real-time scanner-based analysis and update of optimal TI values, in that case based on a direct search algorithm implementation, used for its fast processing speed [3].

This analysis runs within the image processing pipeline on the scanner reconstruction computer, and optimises model parameters online on a masked voxel-by-voxel basis to best-fit the ΔM signal timecourse for *f* and δτ ; considers the distribution of the optimal TIs from all voxels; and in real-time feeds-back a new set of TIs to be run, all in <1 second. These new TIs are then acquired, and voxel fits for all data so far collected are used to iteratively generate an improved set of TIs, and so on for the total number of TI blocks requested. With sufficient blocks there will be convergence of TIs to overall optimised values. The original approach in [3] selected voxels for fitting based on a thresholded range of ΔM signal (e.g.: 0.5 – 1.5%), as approximating a grey matter mask, which is adequate for healthy adult controls, but would fail in disease studies such as stroke where voxel ΔM values fall outside the normal range. This study extends that approach by use of an independent method of voxel mask generation not reliant on the perfusion signal itself, and allows for robust TI optimisation to desired region(s), in future enabling complex online ROI studies, such as specific vascular territory and/or pathological conditions (e.g.: stroke), in which *f* and/or δτ may vary from norm.

Methods and Results: Studies were run on a 3T Siemens Verio system and subjects gave written, informed consent (4 healthy adults, age 31 ± 4). Three different ASL TI acquisition schemes were employed (EDS, ASD1 and ASD2), with 10 TIs across a range of 0.8 to 1.8 seconds. The evenly distributed sampling (EDS) approach had TIs evenly spaced with repeated acquisition as for a standard multi-TI measurement; the ASD1 approach used self-generated voxel mask based on ΔM signal, created during image processing; the ASD2 approach used a prior-acquired image to generate independent voxel masks. To create the mask a double inversion recovery (DIR) GE-EPI sequence [4] was acquired with grey-matter weighting (64^2 voxels at 3x3x6 mm^3; five slices; TI1/2 3.2/0.5 seconds; TR=20 seconds to allow full signal recovery; TE=18 ms; partial-Fourier acquisition 6/8; and flow crusher gradients to destroy signal in large vessels). DIR acquisition took approximately 1 minute at the start of the scan session. DIR images were averaged online and stored in memory for subsequent pulsed ASL scans, performed using the QUIPSS2 technique [5], with TI1 (saturation time of labelling volume) set to 0.7 seconds post-label. The same EPI parameters and slices were used, except for TR (3.2 seconds, therefore 7.4 seconds for control-tag pair). One block of TIs took ~75 seconds. For ASD acquisitions the first set of TIs were fixed and subsequent TI sets were generated using only voxels within the mask. Eight TI blocks were acquired for each approach. An additional ASD2+ run was acquired, using a co-multiplied scanner-generated morphological mask of PCA territory grey matter, with the hypothesis that this region would have longer inflow times, and thus that optimal TIs would fall later in time. The total scan duration was ~50 minutes for all comparisons. The online TIs were recorded, and final data sets were fitted to the Buxton model offline in Matlab for *f* and δτ.

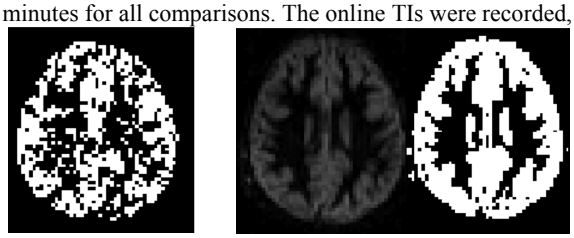

Figure 2: ASD1 ΔM-generated mask vs. ASD2 GM DIR image -> mask; both masks created online in the Siemens ICE recon pipeline

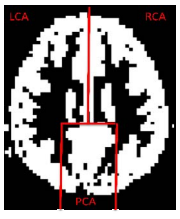

Figure 3: ASD2+ Mask segmentation

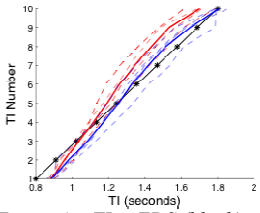

Figure 4a: TIs - EDS (black), ASD1 (red), ASD2 (blue)

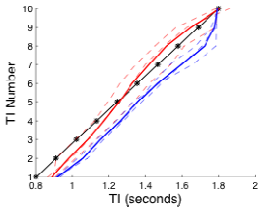

Figure 4b: TIs - EDS (black), ASD2 (red), ASD2+ (blue)

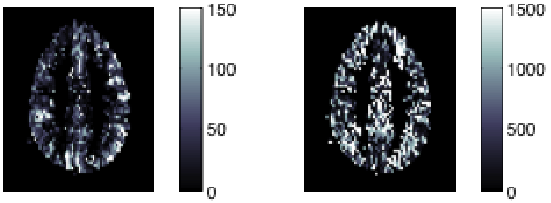

Figure 5: CBF (m/100g/min) and δτ (ms) maps from ASD2

Fig. 4 plots the end block TIs for the different approaches, showing similarity between global ASD1 and 2 (a) and the later TIs for ASD2+ only compared to global GM for 3 subjects (b) [dotted lines are individual subjects; bold shows mean values]. Averaging *f* and δτ across all slices and subjects it was found:

	EDS	ASD1	ASD2	ASD2+
f (ml/100g/min)	53 ± 12	55 ± 13	55 ± 11	62 ± 7
δτ (ms)	431 ± 104	391 ± 70	432 ± 92	492 ± 112

Values are comparable to literature; ASD2+ has increased δτ as expected.

Discussion: Using DIR images to create online tissue masks improves tissue specificity for online, real-time TI optimisation with ASD, independent of the ΔM signal. Simple segmentation has been shown to weight optimal TIs for specific brain regions, with the ASD2+ scheme optimising to longer TIs, as expected from the increased δτ. Future work will integrate more complex segmenting options and will apply the technique to study stroke patients where perfusion can be regionally impaired. It is also possible to use DIR to generate alternative tissue masks (e.g.: white matter, which is not possible with ASD1 approach) and WM ASL is of increasing interest as studies move to higher field strength.

References: 1 – Buxton, MRM, 1998; 2 –Xie, MRM, 2008; 3 – Xie, MRM, 2010; 4 – Redpath, BJR, 1994; 5 – Wong, MRM, 1998. Funded by the MRC.