Whole brain quantification of arterial transit time and perfusion using multi-slice pseudo-continuous arterial spin labelling

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Introduction: Whole brain quantitative imaging of cerebral perfusion provides a means to assess and characterize neurodegeneration[1]. Given that arterial transit time (tA) varies across the brain and may be prolonged in disease, accurate estimation of perfusion (f) by arterial spin labelling (ASL) requires adequate sampling of the time course for accumulation of labelled spins in the tissue. In particular, a range of post-label-delays (PLDs) including those that precede the difference signal peak are required for robust estimation of tA and by extension perfusion. However, even with rapidly acquired slices (~40ms per slice), slices in the top third of the brain will be acquired at delays upwards of 600ms, too late for estimation of tA and having lower SNR. To address the issue of poor time-delay sampling of distal slices in traditional multi-slice acquisitions, we propose a novel slice ordering approach to multi-slice pseudo-continuous ASL (pCASL)[2].

Methods: In the slice reordering (Round Robin) scheme, the time at which a given slice is sampled is permuted after each pair of control-label images. Following a pair of dummy scans to achieve steady state, slices are acquired from most superior slice first, to most inferior slice last for a pair of control-label images. For the next pair, slice order is incremented such that the 2nd most superior slice is acquired 1st, the most inferior slice is acquired 2nd last and the most superior slice is acquired last. This permutation continues until every slice is sampled at every achievable PLD (determined by the number of slices and slice timing). Two limitations to this approach arise due to the effect of changing slice order on effective repetition time (TR) for a given slice. First, when a slice switches from being acquired first to being acquired last, the effective TR for static tissue spins is (# of slices – 1) x (slice time) greater than normal for that image. As this only occurs with the pair of images acquired for the longest PLD, we address the limitation by dropping this data point from the analysis. The second limitation is that there is a slight difference (equal to slice time) in effective TR between control and label images within a pair. However, because TR is generally greater than 3 times the T_1 of blood and tissue, this effect may be ignored. Figure 1 compares the sampling range of a traditional multi-slice acquisition to an equivalent Round Robin acquisition. It is readily apparent from this plot that over half the slices acquired with a traditional approach do not or only barely sample the signal peak.

MRI data were collected with a 1.5T MRI system (Signa EXCITE HD, GE Medical). The scanning protocol included a 2D time-of-flight MRA scan to facilitate label plane prescription, followed by a 3D FSPGR sequence for anatomical reference. The pCASL sequences employed a 5mm labelling plane positioned perpendicular to the internal carotid arteries. Labelling comprised a series of 1000 slice-selective Hanning-shaped RF-pulses with a flip angle of 35° and a spacing of 1.5ms. Slices were 5mm thick with an in-plane resolution of 3.75x3.75mm and 5mm slice gap.

Three datasets (limited to 10 minutes of scanning each) were acquired in a healthy 20 year-old male (TR/TE = 5s/23ms) – A) **Single slice** (MNI z=34) – Benchmark dataset acquired with 10 different PLDs from 50 to 1400ms and 5 control-label repeats per PLD. B) **Traditional** – Whole brain (19 slices, center @ MNI z=34), slice-to-slice time = 60ms, the same PLDs and number of repeats as the single slice data. C) **Round Robin** – Same prescription as B, slice-to-slice time=100ms and 18 PLDs from 50 to 1750ms, 3 repeats. Data were in-plane motion corrected using AFNI's 2dImReg. The MNI grey matter structural atlas was aligned into subject space using FSL's Flirt. Regions of interest were defined using the structural atlas and a 1% mean difference threshold. Regional f and tA were estimated using a non-linear robust estimator and the fast two-compartment model described in Parkes et al[3].

Results: Figure 2 displays representative mean percent difference signal and parameter estimates for the parietal grey matter for the three acquisition approaches. The Round Robin approach resulted in comparable estimates to the benchmark single slice data. Conversely, due to slice timing delays, data acquired with the traditional multi-slice acquisition did not adequately sample the signal peak, resulting in an erroneous estimate for tA. Distal slices where the peak was not sampled led to poor parameter estimates with the traditional acquisition.

Conclusions: Traditional whole brain multi-slice acquisition schemes for ASL are sensitive to slice timing delays which can result in poor parameter estimates for superior regions of the brain. The proposed Round Robin approach to multi-slice imaging resolves this issue by sampling all slices in the brain across an equal range of delays without increasing total scan time.

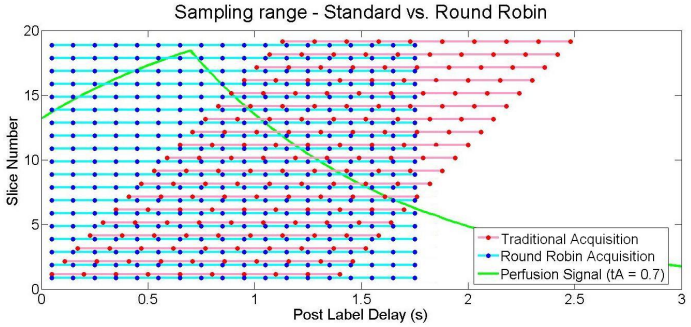

Figure 1 – Sampling range of traditional and round robin acquisition schemes. Underlay is the signal curve for a hypothetical perfusion signal (tA = 0.7s)

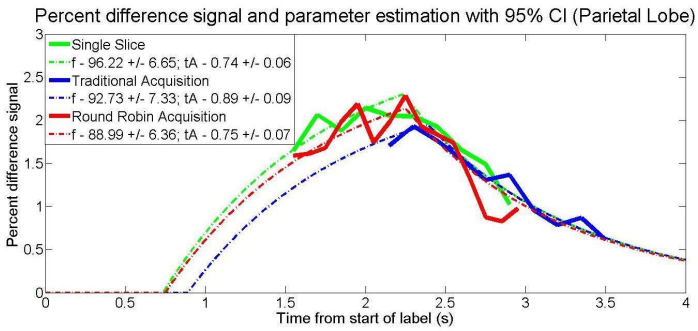

Figure 2 – Comparison of acquisition methods. (MNI z=34)
Perfusion (f) is in ml blood / 100ml tissue / min; Transit time (tA) is in seconds.

References: [1] Yoshiura et al., AJNR 2009. [2] Garcia et al., Proc 13th ISMRM, 9, 2005. [3] Parkes et al., MRM, 48:27-41, 2002.