Saturated label effects with multi-slice imaging in ASL

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Introduction: Conventional practice for whole brain cerebral perfusion imaging using arterial spin labelling (ASL) is to acquire consecutive transverse slices from the inferior to the superior aspect of the brain. When implemented with continuous labelling of the carotid arteries at the level of the neck, increased transit time to the superior-most slices is partially offset in this acquisition scheme by a longer delay following labelling in acquiring the superior-most slices. However, when consecutive slices are acquired at equivalent post-label-delay (PLD) a confound associated with ascending slice order becomes evident. Labelled blood that is intravascular and transiting to a distal slice can be saturated during the imaging of proximal slices. Typical EPI slice acquisition times on the order of 40 ms and interslice gaps of 1mm are respectively too long and too small for the ascending slice acquisition to outpace even slow moving blood of 4cm/s. Here we present data showing the magnitude of this effect and assess the implications for perfusion estimates with three different acquisition schemes.

Methods: 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 pseudo continuous ASL[1] 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. A large slice gap of 5mm was used to provide a conservative estimate of the proximal saturation effect based on 'faster' moving blood (E1 > 8cm/s, E2 > 5cm/s).

EXPERIMENT 1 (E1) – Effect of proximal saturation: 7 datasets were acquired in a healthy 20 year-old male. Each dataset consisted of 7-19 slices acquired inferior to superior, with 15 control-label pairs acquired (TR/TE = 4s/23ms, slice-to-slice time = 60ms). The number of inferior slices acquired before the slice of interest (MNI z = 10) was varied from 0 to 6 while the post-label delay (PLD) time for this slice was maintained at 600ms.

EXPERIMENT 2 (E2) – Effect on perfusion estimation: 3 datasets were acquired in a healthy 22 year-old female. The single slice (SS) dataset is free of saturated label effects, and consisted of a single slice (MNI z=34) acquired with 10 different PLDs from 50 to 950ms and 5 control-label repeats per PLD (TR/TE = 5s/23ms). The other two datasets were acquired using a Round Robin multi-slice acquisition sequence where each slice is imaged for the same set of PLDs. This is achieved by permuting the order in which slices are acquired after every control-label pair, specifically by shifting the order inferior or superior by one slice. These data consisted of 11 slices with the same center slice and PLDs as the SS dataset (slice-to-slice time = 100ms). These two datasets differed in slice acquisition order, inferior-to-superior (IS) and superior-to-inferior (SI) and three repeats were acquired for each.

All data were corrected for in-plane motion 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 using the 0-inferior slice dataset for E1 and across all PLDs for the datasets of E2. For E2, regional f and tA were estimated using a non-linear robust estimator and the fast two-compartment model described in Parkes et al.[2]

Results: Figure 1 demonstrates a significant decrease in the mean percent difference signal with an increasing number of previously acquired inferior slices ($p<0.0001$). For example, the difference signal drops by 22% with 5 inferior slices. Figure 2 displays representative mean percent difference signal and parameter estimates for the frontal grey matter in E2. The tA confidence intervals for all three datasets overlap; however, perfusion estimates of the IS data are significantly lower than those of either SS or SI acquisitions. The 21% lower perfusion estimate found with IS relative to SS is comparable to the reduction in difference signal predicted by the first experiment.

Conclusions: Inferior-to-superior multi-slice acquisition schemes can affect labelled blood in ASL sequences. This effectively decreases label efficiency, resulting in smaller difference signals and potentially underestimated perfusion. This effect can be avoided by acquiring multi-slice data in the superior-to-inferior direction using the Round Robin acquisition approach.

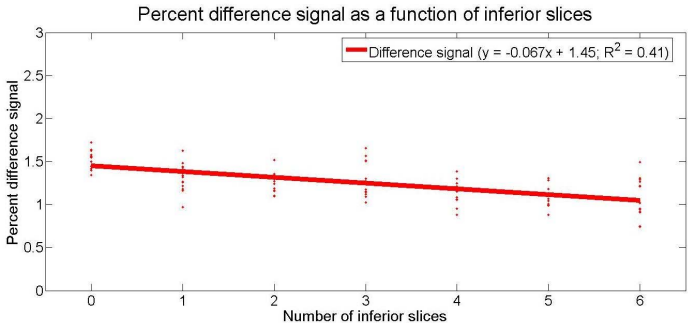

Figure 1 – E1: Percent difference signal as a function of preceding acquired inferior slices (grey matter, MNI z = 10). PLD for was 0.6s for all data.

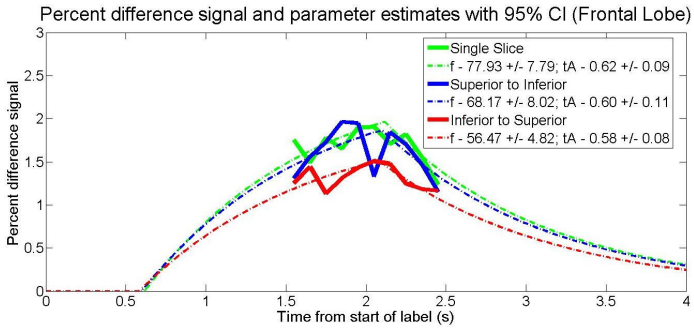

Figure 2 – E2: Impact of acquisition order on perfusion estimates. (MNI z=34) Perfusion (f) is in ml blood / 100ml tissue / min; Transit time (tA) is in seconds.

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