Effects of Activation Induced Transit Time Changes On Functional Turbo ASL Imaging

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Introduction

Recently, a few methods for acquiring arterial spin labeling (ASL) perfusion images at a greatly reduced TR compared to traditional schemes have been introduced [1-3]. These "turbo" methods all work on the basic premise of tagging spins for a shorter period of time such that a control image can be acquired immediately after the tagging period. The tag reaches the slice the following TR, during which the tag image is acquired. These techniques can be used for mapping functional activations at higher temporal resolution than is possible using standard ASL techniques.

A concern with such turbo ASL techniques, however, is that the optimal choice of TR depends on the transit time of the label to the voxels of interest. The largest perfusion signal is seen for a TR equal to the (arterial) transit time. Choice of an improper TR will result in reduced perfusion signal. In addition, it has been shown [4,5] that a change in transit time on the order of 10% occurs upon functional activation. This means that the optimal turbo ASL TR is different for the baseline and active states. This could result in either increased or reduced relative changes in CBF being observed as compared to the true CBF change as demonstrated in Figure 1. The curves in this figure were produced using a modified form of Buxton's convolution based model [6] as described in [1]. For each TR in the simulation, the tagging duration was set to TR-180ms.

Methods

In order to measure the dependence of the amplitude and shape of the functional response to choice of TR a human subject was scanned on a 3 T GE Signa LX scanner. A two-coil system was used to perform spin labeling. Initially, the subject was briefly scanned using the turbo ASL technique for TR values of 1, 1.1, 1.2, 1.3, 1.4, 1.5, and 1.6 s. The TR with the optimal signal strength (1.4s) was chosen and this TR was then assumed to be the resting state transit time. All scans used the following sequence parameters unless otherwise listed: SE, TE=12ms, FOV=20, spiral readout, 3 adjacent 7mm slices, resolution 64x64.

Next, the subject repeated an identical finger tapping paradigm ([20s rest, 10s tapping] x 12) six times. Five of these were turbo CASL acquisitions and one was a standard 4s TR CASL acquisition (GRE, 18ms TE). For the turbo CASL acquisitions, one was performed at the measured resting state transit time of the subject while the others were performed at +/-10% and +/-20% of this value. Control and tag image timeseries were each upsampled by two using sinc interpolation before subtraction. Active voxels were identified by correlation to a reference waveform. Timeseries were compared across the different turbo ASL acquisitions using an unbiased set of voxels taken from the 4s TR acquisition (r>0.35).

Results

The resulting average timeseries responses to activation are shown in Figure 2. These responses have been normalized to the baseline perfusion signal. The relative signal changes were measured to be 110, 67.0, 42.1, 19.6, 13.4, and 49.1% for TRs of 1.12, 1.26, 1.4, 1.54, 1.6, and 4s respectively. The baseline CBF signal amplitudes over the active voxels for these same TR values were 8.24, 13.2, 16.3, 18.3, 14.8, and 39.0. The trend in relative changes observed agrees with those in the simulation of Figure 1. Figure 3 demonstrates that some voxels display significant functional signal changes for all cases. The location of these voxels was generally in the same regions, but only partially overlapping.

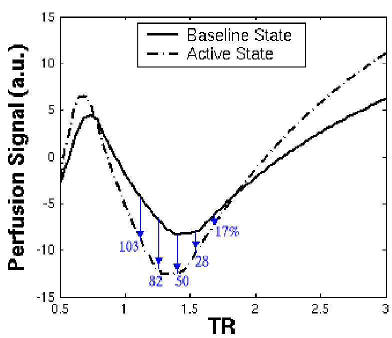

FIG 1: Simulated signal vs TR for two states. The baseline has TR=1.5s. The active state has a 50% larger CBF and a reduced transit time of 1.39s. Blue numbers indicate % signal changes for various TRs.

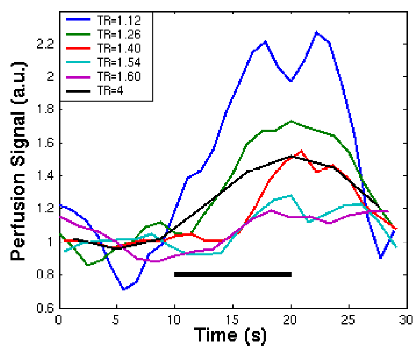

FIG 2: Normalized average functional responses over slice 3 to the finger tapping paradigm. The dark bar at the bottom indicates when the task was performed.

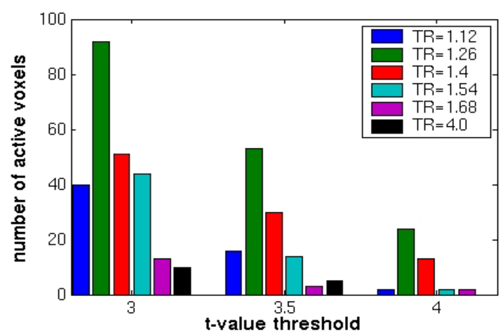

FIG 3: Number of active voxels for t-value thresholds of 3, 3.5, and 4. A TR slightly shorter than the resting state transit time resulted in the most voxels found.

Discussion

The turbo CASL technique was able to reliably detect activations at an improved temporal resolution. The baseline signal amplitude was lower than for a standard CASL acquisition, but the greatly increased number of samples acquired resulted in more significant voxels found by the turbo scheme for most choices of TR. As predicted by the simulation, the percentage signal change observed for a given set of voxels is highly dependent on the choice of TR. This high sensitivity to changes in transit time makes the turbo ASL technique unsuitable for quantification.

This same sensitivity to transit time also affects the maximum number of slices that can be acquired with turbo ASL. A TR that is optimal for one slice will not be optimal for the others due to the delay between when each slice is acquired. Also different brain regions have differing transit times, ruling out the applicability of the technique to whole brain scans comparing regions with significantly different transit times.

Although the data in the current work is derived from two-coil spin labeling experiments, the implications of transit time sensitivity apply equally well to other turbo ASL implementations. The percent signal change was largest for the shortest TR, but at the cost of reduced SNR. Choosing a TR longer than the baseline transit time results in greatly reduced sensitivity to functional activity. Choosing the TR slightly shorter (e.g. 50-100ms) than the resting state transit time results in the most accurate relative signal change upon activation (as demonstrated by the middle arrow of Figure 1). With a proper TR, turbo ASL is not adversely affected by transit time changes and can provide improved sensitivity in functional applications.

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References: [1] Hernandez-Garcia *et al*, MRM (in press) [2] Wong *et al*, MRM **44**, p. 511 (2000) [3] Wong *et al*, Proc. ISMRM 9 p.1162 (2001) [4] Gonzalez-At *et al*, MRM **43**, p.739 (2000) [5] Yang *et al*, MRM **44**, p.680 (2000) [6] Buxton *et al*, MRM **40** p.383 (1998)