Dynamic Changes in Blood Transit Time and Flow during Somatosensory Stimulation Measured by Dynamic ASL with High Temporal Resolution

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Introduction

The blood transit time from arterial spin labeling plane to capillaries in the imaging slice (referred to as "tissue transit time") decreased during neuronal activation in humans (1), while it appeared no changes during somatosensory stimulation in rats (2). Since a tissue transit time is shorter in rats compared to humans, shortening blood transit time may not be detectable with arterial spin labeling (ASL) data with low temporal resolution. Thus, it is important to carefully measure dynamic transit time changes during stimulation. In this work, the dynamics of both CBF and the blood transit time during rat forepaw stimulation were simultaneously measured with a modified dynamic ASL (DASL) method with improved temporal resolution.

Materials and Methods

The original DASL method (3) was modified to increase temporal resolution. The magnetizations of spins in the imaging slice were repeatedly excited with Look-Locker excitations and interval *TI*. Data were collected in a cycle of *N* acquisitions for one cycle, in which the spin labeling pulse was applied for first half, while control images were obtained for the second half (Fig. 1). For measuring tissue transit time, bi-polar diffusion gradients were applied in all three directions with the b value of 50 s/mm^2 to eliminate the arterial blood signal (4). With ASL, magnetization $M(\tau)$ at τ ($\tau=nTI$, $0\le n<N$) is $M(\tau) = M_{eq}[1-\exp(-\tau R'_{1app})] + M(0)\exp(-\tau R'_{1app}) - \Delta M(\tau, f, \delta)$, where M_{eq} is the longitudinal steady-state magnetization (5), $M(0)$ is the initial magnetization in each cycle, R'_{1app} is the apparent spin-lattice relaxation rate in the presence of Look-Locker excitations (6), and ΔM is the magnetization change induced by ASL which can be derived from the general kinetic model (7). ASL images ($M(\tau)$) were acquired with the DASL technique, and R'_{1app} was measured from 20 excitations without ASL. Transit time (δ) and CBF maps (f) were obtained by fitting ASL data with the above-mentioned equation.

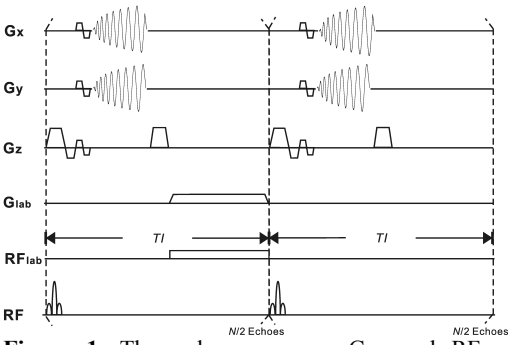

Figure 1. The pulse sequence. G_{lab} and RF_{lab} denote the gradient and radio-frequency pulse for labeling, respectively.

Seven male Sprague-Dawley rats weighing 350–450 g were studied under the 1.5% isoflurane level. Forepaw stimulation was conducted with the block-design paradigm, which consisted of 5 control (20 s), 5 stimulation (20 s), and 10 control (40 s) cycles. MRI experiments were performed on a Varian 9.4 T, 31-cm-diameter system, and actively-decoupled two coils for ASL. Images were acquired with single-shot spiral read-out. Other imaging parameters were: flip angle = 20°, *N*=40, *TI*=100 ms, slice thickness = 2 mm, TE = 6 ms, TR = 4 s, matrix size 64×64, and field of view 2.56 cm×2.56 cm. Cross-correlation coefficient (CCC) maps were obtained using a boxcar cross-correlation method (15 controls and 5 stimulations for CBF, 15 controls and the first stimulation after the stimulus onset for transit time) and "active" pixels were obtained.

Results and Discussion

$M(\tau)$ exponentially decreases during the ASL period, then returns to the baseline condition during the control period in each 4-s DASL cycle (Fig. 2a). During forepaw stimulation, CBF increases in the contralateral primary somatosensory cortex (Fig. 2b), which is indicated by an increase in the difference between minimum and maximum intensities in raw DASL time courses. CBF increase was sustained during the 20-s stimulation period, while tissue transit time changed during the stimulation period, –23.3±9.3% at 2 s and –6.2±7.9% at 6 s after the stimulus onset (Fig. 3). Although CBF increase was observed, transit time change was minimal at a later stimulation time period (>10 s). Our data indicate that dynamic changes in CBF and velocity (i.e., inverse of transit time) are mismatched; the transit time decrease dominates at right after stimulation, while arterial blood vessel dilation dominates at a later time period. Thus, velocity and diameter changes measured with a short stimulation period may not directly applicable to long stimulation periods which often use in fMRI community.

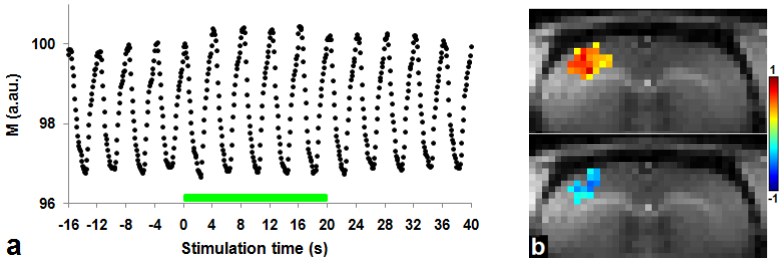

Figure 2. (a) Magnetization responses with respect to part of the time course, averaged from the "activated" pixels in CBF map (the top of b). Green color indicates the stimulation period. (b) Activation maps of CBF (top) and the tissue transit time (bottom). The color bar indicates a range of CCC values.

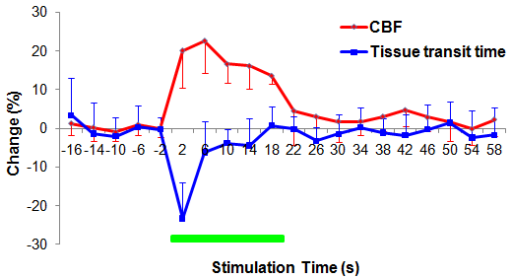

Figure 3. Time courses of CBF and tissue transit time. Green color indicates the stimulation period; error bars (only one side is shown) represent one standard deviation.

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