Simultaneous quantification of cerebral arterial blood volume and flow during visual stimulation in humans at 3 T.

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Introduction

Vascular physiology studies have shown that an increase in cerebral blood flow (CBF) during neural activation is modulated by dilation of upstream *arterial* vessels [1]. Recent studies showed that an increase in arterial cerebral blood volume (CBV_a) is the dominant contribution to the total CBV response [2]. Thus, quantification of stimulation-induced CBV_a response and its relationship with CBF response is essential to understand the hemodynamic mechanisms underlying brain function. Arterial spin labeling (ASL) signals are originated from combined contributions of tissue and arterial vessels that can be separated by use of bipolar gradients. A theoretical framework for the quantification of CBV_a from ASL using bipolar gradients was developed [3]. In the current study, we simultaneously quantified CBV_a and CBF using a pulsed ASL (flow-sensitive alternating inversion recovery, FAIR) with and without bipolar gradients in humans at 3T, and assessed changes in CBV_a and CBF during a visual stimulation.

Methods

Four healthy volunteers were scanned at a 3-T Siemens scanner using a volume head coil and the FAIR technique with and without bipolar gradients (b = 70 s/mm^2). Four images were acquired in the visual cortical areas with matrix size of 64×64, in-plane-resolution of 4×4 mm^2, slice thickness of 5 mm, inter-slice gap of 2.5 mm, slice-selective inversion thickness of 4.8 cm, TE of 29 ms, and TR of 3 s. The measurement of CBV_a requires labeled spins fill up arterial vessels. When the spin labeling duration is longer than the blood transit time from the labeling plane to arteries at imaging slice (τ_a) but shorter than the transit time to capillaries (τ_c), the arterial blood dominates in the ASL signal. τ_a and τ_c of the gray matter are ~0.9 s [4,5] and ~1.4-1.9 s [4-6], respectively. Thus, 1.1 s and 1.4 s of inversion time (TI) were used. For the visual stimulation, 36-s binocular, large-field, white/black flashing checkerboard stimuli at 8 Hz were used, and two fMRI runs were repeated. CBV_a was calculated according to $v_a = [\Delta S(0)/S_0(0) - \Delta S(b)/S_0(b)]/[2\alpha_a \cdot \xi - \Delta S(b)/S_0(b)]$[3], where $\xi = e^{-(R_{2(artery)}-R_{2(tissue)})\cdot TE}$, ΔS(b) and ΔS(0) are changes in signal associated with the stimulation with and without bipolar gradients, respectively, and α_a is the arterial spin labeling efficiency (i.e., 0.95). R_2 of arterial blood and tissue water at 3 T is 16.66 and 22.22 s^{-1}, respectively [7]. CBF was calculated using a single-compartment model from the data at TI of 1.4 s.

Results and Discussion

The baseline CBF and CBV_a maps and corresponding functional signal change maps were successfully obtained from all measurements (**Fig. 1**). The baseline CBV_a and functional changes obtained at TI = 1.1 s and 1.4 s were similar (data not shown) except for a higher sensitivity for TI of 1.1 s. The baseline CBV_a maps from two repeated measurements were highly reproducible (r = 0.85). **Fig. 2** shows averaged time courses of ΔCBF and ΔCBV_a from all active pixels. Average CBV_a and CBF changes were dynamically synchronous and highly overlapping during visual stimulation, suggesting that arterial vessel dilation is the major mechanism of CBF increase.

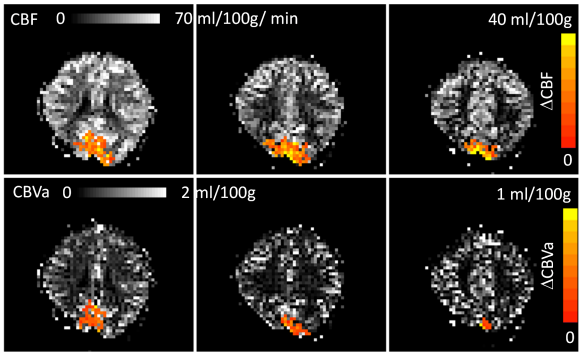

Fig. 1. Quantitative CBF and CBV_a baseline and functional responses to visual stimulation. Baseline values in all maps are higher in gray matter than in white matter. Quantitative CBF (above) and CBVa (below) functional activation maps are overlaid in color (Color scale bars in right side shows absolute functional change) on the grayscale of baseline maps from three contiguous slices.

Since CBV_a is an important contributor to the total CBV, the FAIR with bipolar gradients is useful to measure CBV repeatedly without the use of exogenous contrast agents. Therefore, this technique can be used to measure baseline CBV_a and assess cerebrovascular viability and pathological conditions.

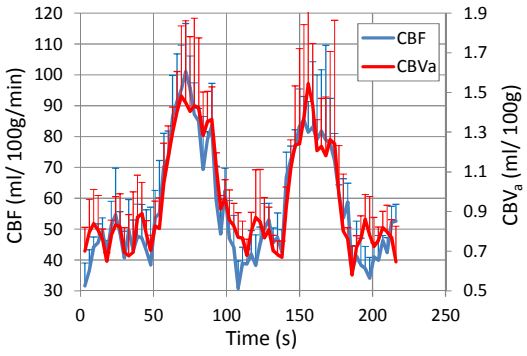

Fig. 2. Quantitative time course of CBF and CBV_a responses to visual stimulation. A tight coupling between CBF and CBV_a changes was observed. Error bars: standard deviation.

References: 1. Iadecola et al., J Neurophysiol 1997, 2. Kim et al, JCBFM 2007, 3. Kim and Kim, MRM 2006, 4. Wang et al., MRM 2003, 5. Ann and Lin, MRM 2003, 6. Ye et al.,MRM 1997, 7. Zhao et al., MRM 2007