Cerebral arterial blood R_2^* and volume measurements during stimulation

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Introduction

Accurate determination of arterial blood T_2^* is important to examine the arterial blood contribution to BOLD fMRI and to quantify arterial blood volume obtained from MRI data. The arterial blood contribution to BOLD fMRI has been ignored because arterial blood has been assumed to be fully oxygenated. Based on recent direct measurements of blood oxygen tension and vessel diameter in isoflurane-anesthetized rats (3), arterial oxygen saturation was found to be ~85% in small pial arterial vessels much less than the systemic value of 97%, and increased during somatosensory stimulation, and also found the dilation in arterial, not venous, vessels was observed, which is consistent with MRI measurements (4). In previous arterial CBV measurements, the transverse relaxation difference between arterial blood and tissue was ignored (5). To examine two above-mentioned assumptions, R_2^* values and blood volumes of arterial blood in baseline and activation conditions were measured using the continuous arterial spin labeling (ASL) technique with a short labeling duration of 700 ms.

Methods

Five male Sprague-Dawley rats weighing 350-450 g were studied on a 9.4-T MRI (Varian) system. Throughout the experiments ~1.4% isoflurane-anesthesia was administered with an inhalation O_2 level of ~30%. Animals were maintained within normal physiolo gical conditions. Forepaw stimulation of 15-s duration was performed with 1.0 ms pulse width, 1.1 - 1.4 mA current and 12 Hz frequency (5). Two actively detunable RF coils were used; a neck coil for ASL, while a head coil for imaging. A single 2-mm thick coronal slice covering the forelimb somatosensory area was selected. All images were acquired using the single-shot GE EPI with matrix size of 64 (readout) × 32 (phase-encoding) and FOV = 3.0 × 1.5 cm^2. TR = 2.5-s (700-ms for spin labeling duration and 1.8-s for image acquisition), and TE = 6, 10, 15 and 20 ms were applied. Note that since the arterial blood transit time from labeling plane to capillary is 600 – 700 ms (6) and the water exchange time between capillary and tissue is ~500 ms, labeled spins fill mostly the arterial vasculature (before exchanging with tissue) during 0.7 s. The somatosensory ROI was defined from the area contralateral to stimulation. R_2^* of tissue and arterial blood was determined by the slope from a linear fit of log(unlabeled signal) vs. TE, and log(ASL signal) vs. TE, respectively. Arterial blood volume fraction can also be calculated by the intercept from a linear fit of ASL signal.

Results

Fig. 1 shows tissue (unlabeled) (A) and ASL signals (B) vs. TE during baseline (blue) and stimulation (red) conditions. The measured R_2^* of tissue was 37.1 ± 7.1 s^{-1} and 36.7 ± 7.2 s^{-1} (n = 5), and that of arterial blood was 53.5 ± 15.3 s^{-1} and 50.3 ± 12.8 s^{-1} (n = 5), in baseline and stimulation conditions, respectively. Time courses of R_2^* changes were plotted (Fig. 2). The decreased R_2^* in tissue signal was consistently observed in all animals, while large inter-subject variations were seen in arterial blood. The R_2^* change in arterial blood is not significant during stimulation.

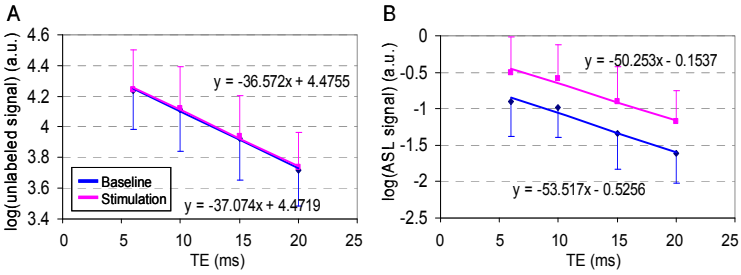

Fig. 1. Linear fit of tissue signal (A) and arterial blood (B) in baseline (blue lines) and stimulation (pink lines) condition. Error bars: standard deviation. a.u.: arbitrary unit

The arterial blood volume was 0.64 ± 0.23 ml/100g and 0.93 ± 0.23 ml/100g (n = 5) in baseline and stimulation conditions, respectively; these values agree well with previous measurements (4).

Discussion

Since R_2^* of arterial blood is larger than tissue R_2^* at 9.4 T, an increase in arterial CBV will decrease the BOLD signal, while a slight decrease in arterial R_2^* increases the BOLD signal. If GE BOLD fMRI is performed at TE of 20 ms (expected 0.8% BOLD signal in tissue), an arterial CBV increase of ~0.3 ml/100g will decrease ~0.08 % to BOLD signal, while an arterial R_2^* decrease will increase ~0.06% to BOLD signal. Thus, an arterial blood contribution to BOLD fMRI is minimal. In terms of arterial CBV quantification, the assumption of similar R_2^* of tissue and arterial blood underestimates arterial CBV by ~20% with TE = 20 ms at 9.4 T. Thus, at relatively short TE, the difference of R_2^* between arterial blood and tissue can be ignorable.

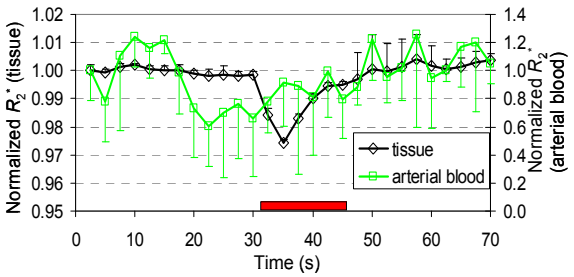

Fig. 2. Normalized time course of tissue and arterial blood signals. Error bars: standard deviation. Red bar: 15-s stimulation period.

References 1. Duong et al., MRM 49, 1019-27 (2003). **2.** Ugurbil et al., Trends Neurosci. 26, 108-114 (2003). **3.** Vazquez et al., JCBFM 30, 428-439 (2010). **4.** Kim et al., JCBFM 27, 1235–1247 (2007). **5.** Kim et al., NeuroImage 52, 224-233 (2010). **6.** Kim and Kim, MRM 55, 1047-1057 (2006). 7. Eichling et al., Circ. Res. 35, 358-364 (1974)
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