Cerebral arterial blood quantification with simultaneous multi-slice acquisition

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Target Audience: Researcher in cerebraovascular physiological imaging

Purpose: The brain maintains adequate cerebral blood flow (CBF) by adjusting the vessel diameters of arteries and arterioles. Our recent study demonstrated that CBF remains constant despite a decrease in cerebral arterial blood volume (CBV_a) in the early-stage of cerebrovascular alterations[1]. Thus, CBV_a can be a more sensitive index than CBF for identifying and assessing cerebrovascular risk factors, and its reduction may be an early predictor of altered CBF. However, whole brain coverage, necessitating multiple sections of CBV_a, is important to assess regional cerebrovascular deterioration properly. The measurement of CBV_a requires labeled spins to completely fill the arterial vessels. The spin labeling duration is longer than the blood transit time from the labeling plane to the arteries (τ_a) at the imaging slice, but shorter than the transit time to the capillaries (τ_c). Thus, the labeling time (i.e., inversion time (TI)) should be longer than the transit time to capillaries (Fig. 1). After the labeled bloods pass through artery (LD), the fresh spins start to fill arterial vessels. When τ_c < TI < LD, CBV_a should be independent of the labeling time. However, this range of TI is not long enough to acquire enough slices to cover the whole brain with the conventional 2D EPI data acquisition. Recently, multiband (MB) excitation and reconstruction was developed to either boost the speed or the coverage of data acquisition within a given repetition time[2,3]. In this study, we implemented and tested MB acceleration to CBV_a measurements based on the arterial spin labeling (ASL) technique, and compared results with those obtained using the conventional single-band (SB) method.

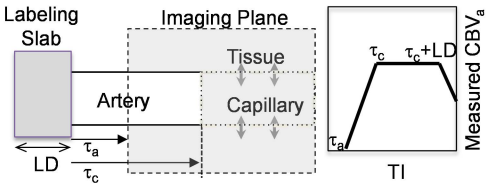

Fig. 1. The schematic diagram of labeled spins with TI for CBV_a measurement

Methods: Six healthy volunteers were studied on a 3-T Siemens scanner using a 32-channel head coil. Interleaved control and tag images were acquired with single-shot gradient-echo, EPI with matrix size = 64 × 64 and FOV = 23 × 23 cm^2, TR/TE = 3 s/30 ms, and 20-25 data average. The separation between the arterial blood and tissue signal can be achieved using bipolar gradients[4]; b = 70 s/mm^2 of bipolar gradient is enough to remove fast moving arterial blood[5]. Quantitative CBV_a can be determined by comparing ASL signals obtained with and without suppression of arterial blood signals as follows, CBV_a (ml/100g) = $\lambda\cdot[\Delta S(0)/S_0(0)\text{-}\Delta S(b)/S_0(b)]/[2\alpha\cdot\xi\text{-}\Delta S(b)/S_0(b)]$[4]. To facilitate the direct comparison between the SB and MB methods, we aligned the centers of the image planes for the two methods with each other (Fig.2A). We applied the same slice-selective inversion size and location (2 cm wider than the imaging slab thickness of MB) for labeling in both SB and MB acquisitions. For comparison between MB and SB, MB factor=3, i.e., simultaneously excited 3 slices, was applied to shorten the imaging acquisition time (n=3). A slice thickness = 4 mm and interslice gap = 1 mm were used. A field of view/3 shift using CAIPRINHA was applied to improve the MB reconstruction de-aliasing efficiency[3]. The dependency of the spin labeling duration on CBV_a quantification was also investigated with TI = 0.8, 1.0, 1.2, 1.4 and 1.6 s using MB acceleration factor = 5 (total number of slices = 20) (n=3).

Results and Discussion: Fig. 2B shows the comparison of CBV_a maps from the SB and MB (center 8 slices, red lines in Fig. 2A) acquisitions. All maps from the MB acquisition were successfully obtained and agreed well with those from the SB excitation. A pixel-wise comparison of the CBV_a values between the SB and MB ASL methods are shown in Fig. 2C. The CBV_a values between the two methods strongly correlated; the CC values encompassed a range of 0.87 – 0.92 for all subjects. Fig.3 shows CBV_a quantification with various TIs. Since EPI readout for one slice takes 50 ms, readout for 4 slices within a MB slab (e.g. green box in Fig.4) takes 200 ms, which consequently covers for whole brain volume using MB. If TI > τ_c, CBV_a in the same slice (shown as same color of symbols in Fig.3) should be same. Thus, the optimal range of TI for CBV_a measurement was 0.95 – 1.55 s (Fig, 3). τ_c of the gray matter agrees with the previous reports that is ~0.9 - 1.1 s[3-4]. Fig.4 demonstrates CBV_a quantification maps increasing with the spin labeling duration. The results of this study show that using the MB technique makes it possible to acquire CBV_a for the whole brain for a given short duration of optimal TI acquisition window.

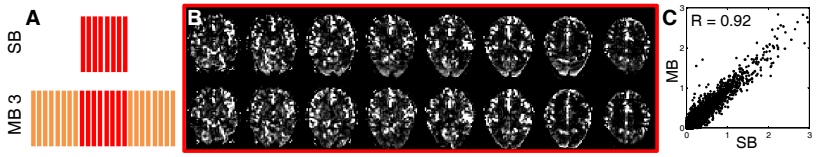

Fig. 2. (A) a diagram of SB and MB ASL acquisition strategy. **(B)** Comparison of SB and MB CBV_a maps. The quality of CBV_a maps acquired by MB acquisition is highly comparable with that by the SB method. **(C)** Pixel-by-pixel comparison between SB and MB acquisitions is highly correlated.

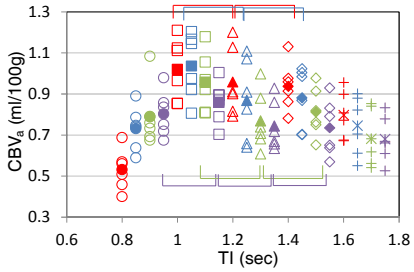

Fig. 3. The dependency of the spin labeling duration on CBV_a quantification. Values are obtained from maps in center MB slab (green box in Fig. 4). Same color: same slice, but measured with different TI. Bracket symbols: statistically no difference. Closed symbols: averaged signal

References: 1. Kim et al., JCBFM In Press. 2. Moller et al ., MRM 2010; 63:1144 3. Setsompop et al., MRM 2012;67:1210. 4. Kim et al. MRM 2006; 55:1047. 5. Wang et al. Neuroimage. 2003; 19:1449. 6. Ye et al. MRM 1997;37:226. 7.Wang et al. Neuroimage 2003;19:1449.

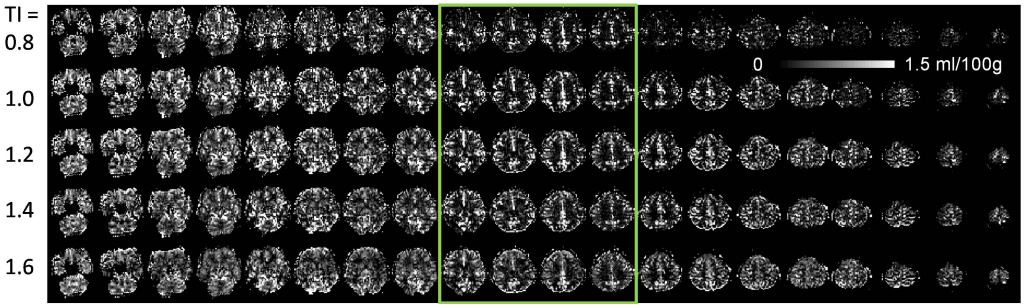

Fig. 4. CBV_a quantification maps acquired using MB acceleration factor = 5 with various TIs.