Quantitative Mapping of Cerebral Blood Flow with Alternate Ascending/Descending Directional Navigation (ALADDIN)

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Introduction: Arterial spin labeling (ASL) has been used to map blood flow noninvasively. Of late, a new imaging technique, termed alternate ascending/descending directional navigation (ALADDIN), was developed for perfusion-weighted (PW) imaging [1] that is based on the interslice blood flow. The technique has potential for high sensitivity to perfusion signals and perfusion directionality [1]. Knowledge of perfusion signal responses to variation of scan parameters is crucial for the optimization and validation of quantitative mapping of ALADDIN signals. In this study, we theoretically and experimentally investigated the effects of RF power (i.e., flip angle) on ALADDIN PW signals and their quantitative aspects.

Theory: Based on a continuous ASL model [2], cerebral blood flow (CBF) in ALADDIN can be expressed as follows:

$$CBF = \frac{\Delta S_{PW}}{M_0} * \frac{\lambda}{2 \cdot \alpha \cdot T_{1app}} * \frac{1}{\sum_{i=1}^{N_{eff}} \exp(-w(i)/T_{1app})} * \frac{1}{(1-\exp(-\tau_0/T_{1app}))} * \frac{1}{D} \quad (1)$$

where ΔS_{PW} is the signal difference between ascending and descending acquisitions; M_0 is the MT-free baseline signal; λ is the brain/blood partition coefficient; α is the labeling efficiency in one prior slice; T_{1app} is the longitudinal relaxation time in the presence of flow and macromolecular saturation; τ_0 is labeling duration (i.e., image acquisition time) of one prior slice; D is the ratio of normalized contrast reduction due to multiple excitations of bSSFP in a slice of interest; and $w(i)$ is the post-labeling delay time for the i-th prior slice. α and D were calculated using Bloch equations for bSSFP [3] for blood and tissue, respectively.

Material and Methods: All experiments were performed on a 3T whole body scanner (Siemens Medical Solutions, Erlangen, Germany) with body coil transmission and 12-element head matrix coil reception (N=3). ALADDIN PW imaging [1] was performed with imaging parameters of TR/TE = 4.1/2.1 ms, matrix size = 128 × 128, FOV = 230 × 230 mm^2, thickness = 5 mm, gap = 7 mm, scan direction = axial, delay time between repetitions = 8–10 sec, and scan time per dataset = ~2.5 min. Flip angle (FA) dependent study was performed by varying FA from 15° to 90° with 15° step. MT-free images (M_0) were acquired with the positive slice-select gradient, ascending order, 8 s inter-slice delay time, and scan time of ~1 min. ROI analysis was performed in a whole gray matter region manually segmented from the center slice. Simulations of Bloch equations were performed to determine α for blood spins with velocity 2–30 cm/s with 1 cm/s step and phase evolution angle from –180° to 180° with 12° step, all of which were eventually averaged for quantitative CBF mapping, and to determined D for on-resonance static tissue spins. For the simulations, T_1 and T_2 values of blood were 1930 ms and 250 ms, respectively, and T_1 and T_2 values of tissue were 1830 msec and 99 msec, respectively [4]. Pulsed ASL was performed for comparison [5].

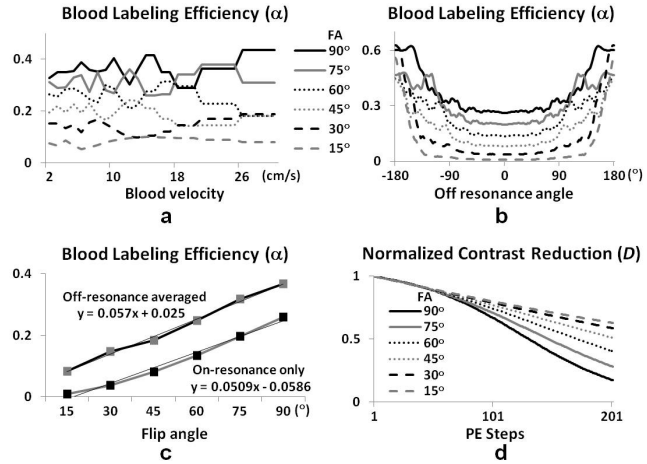

FIG. 1. Simulation results for blood labeling efficiency as a function of blood velocity (**a**), off-resonance angle (**b**), and flip angle (**c**), and normalized contrast reduction factor as a function of PE steps (**d**).

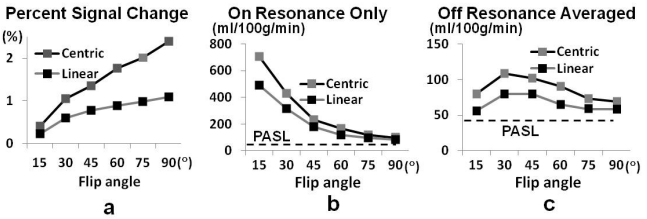

FIG. 2. Experimental results for percent signal changes (**a**) and quantitative CBF measurements in gray matter based on labeling efficiency from on resonance only (**b**) and from off-resonance spins averaged (**c**).

Results and Discussion: Blood labeling efficiency was relatively consistent with flow velocity (Fig. 1a), higher for off-resonance flow spins than on-resonance flow spins (Fig. 1b), and increased with flip angle (Fig. 1a–c). The enhancement of blood labeling efficiency for off-resonance spins was relatively higher at lower flip angles (Fig. 1b,c). Normalized contrast reduction (D) decreased with RF excitations, which was faster at higher flip angle, indicating an advantage of centric PE order over linear PE order (Fig. 1d). Experimental results also showed continuously increasing PW signals with flip angle up to 90°, in agreement with the simulations results (Fig. 2a). Centric PE order showed about twice higher PW signals than linear PE order (Fig. 2a). When blood labeling efficiency was calculated as an average over off-resonance blood spins, mean CBF values were relatively consistent across flip angles and PE orders tested. Values were slightly higher than that from PASL (Fig. 2c), while they were significantly overestimated when blood labeling efficiency was calculated only for on-resonance blood spins (Fig. 2b). Figure 3 shows CBF maps from a representative subject. The perfusion signals were stronger in GM than in WM, consistent with the conventional methods.

High percent signal change (PSC) in ALADDIN PW images may be due to high signal enhancement of off-resonance flow spins in bSSFP [3] as well as existence of multiple labeling planes. Flow spins can deviate from on-resonance due to variations in resonance frequencies across slices, gradient imperfections, etc. Further studies are necessary to experimentally investigate the distributions of off-resonance flow spins and thus to improve the accuracy of CBF quantifications with ALADDIN PW imaging.

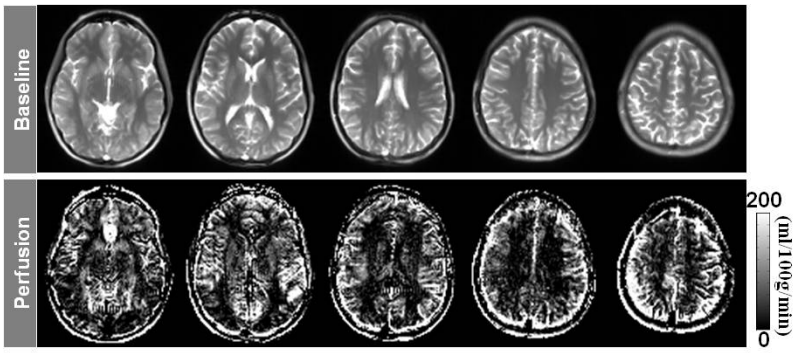

FIG. 3. ALADDIN images for baseline (top row) and quantitative cerebral blood flow (bottom row) from a representative subject. Flip angle = 75°, PE order = centric. ST=~3min.

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References: 1. Park and Duong, Magn Reson Med 2011;65:1578-1591. 2. Williams DS, Methods Mol Med 2006;124:151-173. 3. Markl et al, Magn Reson Med 2003;50:892-903. 4. Stanisz et al, Magn Reson Med 2005;54:507-512. 5. Luh et al, Magn Reson Med 1999;41:1246-1254.