Simultaneous Acquisition of Interslice Blood Flow, Magnetization Transfer Ratio Asymmetry, and MTR

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Introduction : Radio frequency (RF) pulses used for arterial spin labeling (ASL) causes off-resonance saturation, i.e., magnetization transfer (MT), which confounds the ASL-based blood perfusion measurement. In nearly all ASL methods, these MT and MT asymmetry effects are not considered as meaningful signals. When MT asymmetry is intentionally unsuppressed, its effect can be determined and potentially used for clinical applications [1]. The asymmetry of the MT effects arises from the mismatch between centers of bulk water and solid-like macromolecules [2]. Therefore, the MT asymmetry from macromolecules may provide distinct information under pathologic conditions different from the MT effects [3]. In the absence of a dedicated preparation pulse, blood perfusion and MT effects commonly occur in multiple-slice 2D imaging [4,5]. These inter-slice blood flow and MT effects may be exploited as new methods for imaging perfusion and MT effects. Of late, an imaging technique termed, alternate ascending/descending directional navigation (ALADDIN) was developed for the acquisition of perfusion-weighted (PW) [6] and magnetization transfer (MT) asymmetry imaging [7], based on the inter slice blood flow and the MT effects, respectively. Since acquisition of MT free images by a long interslice delay time (> 2 times T_1 of tissue) enables mapping of blood flow [8] and MT ratio asymmetry [9] in the conventional units and also potentially MT ratio ($(S_0-S_{MT})/S_0$), we may be able to map these three different quantities simultaneously. In this study, we investigated feasibility of simultaneous mapping of PW, MT ratio (MTR) asymmetry, and MTR.

Material and Methods : All experiments were performed on a 3T whole body scanner (Siemens Medical Solutions, Erlangen, Germany) with a body coil transmission and a 12-element head matrix coil reception. Five normal male volunteers were scanned in this study approved by the local IRB.

The ALADDIN imaging was performed after a correction for gradient imperfection, as described previously [10]. Imaging parameters were TR/TE = 4/2 ms, flip angle = 60° or 90°, matrix = 128 × 128, FOV = 230 × 230 mm^2, thk = 5 mm, gap = 7 mm, PE order = centric, delay time between repetitions = ~8 sec, and scan time per dataset = ~2.7 min. Data reconstructions were performed as described previously [8,9].

The amount of interslice MT effects both at positive and negative frequency offsets were separately simulated for white matter (WM) using a modified two-pool MT model [1] solved with a Runge-Kutta method and WM T1 and T2 of 1084 msec and 69 msec [11]. The cumulative MT effects in edge slices were simulated as a function of number of prior slices.

Results and Discussion : In edge slices, PW signals were not visible until around the 5th −6th slice (middle row in Fig. 1a). According to the MT-related simulations, the differences between the longitudinal magnetization of the 2nd, 3rd, 4th, 5th, and 6th edge slices and the steady state longitudinal magnetization became less than 8.3%, 1.9%, 0.5%, 0.1%, and 0.0%, respectively, of the initial magnetization (Fig. 1b). Since ALADDIN PW signals are ~1% of baseline intensity, the results indicate that the ALADDIN PW signal would be out of transient cumulative MT effects from the 5th−6th slice, which agreed well with the experimental results (middle row in Fig. 1a). In contrast to the PW signals, strong positive MT asymmetry signals were apparent from the 2nd edge slice (bottom row in Fig. 1a), due to the inclusion of both ascending and descending acquisitions in each subtraction term for MTR asymmetry.

Figure 2 shows the quantitative and semi-quantitative mapping of perfusion, MTR asymmetry, and MTR acquired altogether with flip angle 60° and centric PE order from a representative subject, which took about 3.7 min (ALADDIN acq. : ~2.7 min, MT free images : ~1 min). The perfusion signals were stronger in the gray matter (GM) and both the MTR asymmetry and MTR were stronger in WM, consistent with the conventional methods.

There are similarities and differences between MTR asymmetry and MTR (Fig. 2). The former represents the offset of center frequencies between the free water and bound pools and the latter is about the strength of the MT effects overall. Although the two images look similar in normal subjects, they may provide distinct information under pathologic conditions. Coverage of whole brain with a conventional gap value (20% of slice thickness) is possible by acquiring two datasets spatially interleaved to each other, which would take ~7 min. Our proposed method provides readily a full spectrum of MR measurements useful to characterize a wide range of brain pathological conditions and functional evaluation.

FIG. 1. **Transient (cumulative) magnetization transfer effects in edge slices. a**: Edge slices for baseline, perfusion-weighted (PW), and magnetization transfer (MT) asymmetry signals acquired with centric PE order and flip angle of 90°. **b**: MT effects in edge slices simulated at various flip angles. The transient MT effects are in steady state from the 5th or 6th slices, in agreement with the experimental results.
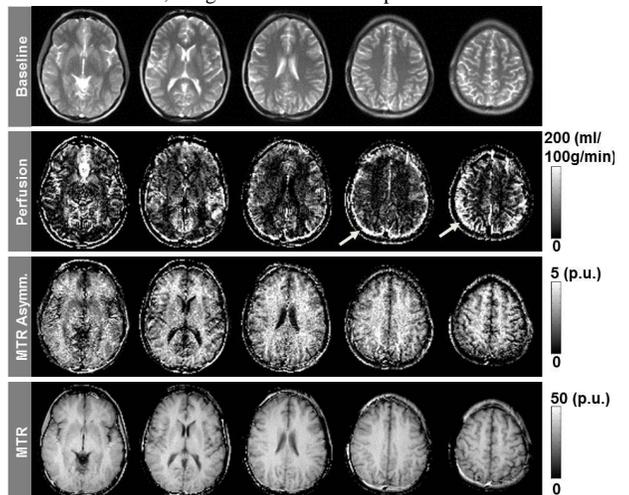
FIG. 2. **Demonstration of simultaneous mapping of blood flow, magnetization transfer ratio (MTR) asymmetry, and MTR with ALADDIN** from a representative subject. The data were acquired with centric PE order. Scan acquisition time : ~2.7 min for ALADDIN acquisition and ~1 min for acquisition of MT free images (total ~3.5 min). The arrows indicate the regions of high vascular signals.

References : 1. Hua et al, MRM 2007;58:786-793. 2. Pekar et al, MRM 1996;35:70-79. 3. Hua et al, Proc ISMRM 2007;15:p882. 4. Williams et al, Invest Radiol 1987;22:642-650. 5. Dixon et al, Magn Reson Imaging 1990;8:417-422. 6. Park and Duong, MRM 2011;65:1578-1591. 7. Park and Duong, MRM 2011;65:1702-1710. 8. Park et al, Proc ISMRM 2012;20:p3492. 9. Park et al, Proc ISMRM 2012;20:p4257. 10. Park et al, MRM 2012;68:1600-1606. 11. St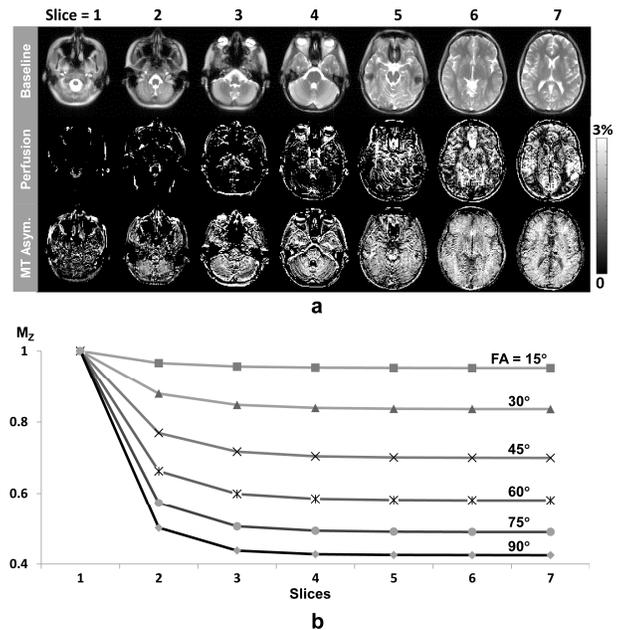anisz et al, MRM 2005;54:507-512.