Correction of Off-Resonance Effects in Multi-Component Driven Equilibrium Single Pulse Observation of T1 and T2 (mcDESPOT)

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INTRODUCTION: Multi-component Driven Equilibrium Single Pulse Observation of T_1 and T_2 (mcDESPOT)[1] is a promising approach for quantifying multi-component relaxation. The method involves the acquisition of spoiled gradient echo (SPGR) and fully-balanced steady-state free precession (SSFP) data over a range of flip angles and, thus, benefits from the high SNR efficiency and rapid acquisition speed of these imaging techniques. However, the use of SSFP also sensitizes the approach to off-resonance effects (unexpected precession of the transverse relaxation during the TR period) which give rise to the oft-observed SSFP banding artifact (Fig. 1 *left*) and results in significant errors in the derived multi-component relaxation parameters (Fig. 1 *right*). Here we describe an efficient technique for minimizing or eliminating this error through the use of RF phase-cycling (incrementing the RF phase along the SSFP pulse train). We show that acquisition of SSFP data with two different phase-cycling patterns permits calibration of the local off-resonance and allows us to remove these effects from the derived mcDESPOT parameter maps.

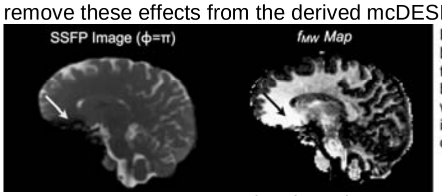

Figure 1: (a) Example of the SSFP banding artifact immediately superior to the sinuses. (b) Effect of the SSFP banding artifact on the calculate myelin water fraction map. Although the artifact is quite localized, its effect is far more disperse on the calculated map.

METHODS: mcDESPOT involves the a 6-parameter fit of the two-component SPGR and SSFP signal models to multi-angle SPGR and SSFP data. The general expression for the two-component SSFP magnetization immediately proceeding each RF pulse is summarized as[1]

$$M_{SSFP} = \left(e^{A_{SSFP}TR} - I\right)A_{SSFP}^{-1}C \cdot \left[I - e^{A_{SSFP}TR}R(\alpha)\right]^{-1}, \quad M_{SSFP} = \left[M_{x,MW} \quad M_{x,FW} \quad M_{y,MW} \quad M_{y,FW} \quad M_{z,MW} \quad M_{z,FW}\right]^T, \quad C = \rho\left[0 \quad 0 \quad 0 \quad 0 \quad \frac{f_{MW}}{T_{1,MW}} \quad \frac{f_{FW}}{T_{1,FW}}\right]$$

$$A_{SSFP} = \begin{bmatrix} -\frac{1}{T_{2,MW}} - \frac{1}{\tau_{MW}} & \frac{1}{\tau_{FW}} & \phi + \Delta\omega_{MW} & 0 & 0 & 0 \\ \frac{1}{\tau_{MW}} & -\frac{1}{T_{2,FW}} - \frac{1}{\tau_{FW}} & 0 & \phi + \Delta\omega_{FW} & 0 & 0 \\ -(\phi + \Delta\omega_{MW}) & 0 & -\frac{1}{T_{2,MW}} - \frac{1}{\tau_{MW}} & \frac{1}{\tau_{FW}} & 0 & 0 \\ 0 & -(\phi + \Delta\omega_{FW}) & \frac{1}{\tau_{MW}} & -\frac{1}{T_{2,FW}} - \frac{1}{\tau_{FW}} & 0 & 0 \\ 0 & 0 & 0 & 0 & -\frac{1}{T_{1,MW}} - \frac{1}{\tau_{MW}} & \frac{1}{\tau_{FW}} \\ 0 & 0 & 0 & 0 & \frac{1}{\tau_{MW}} & -\frac{1}{T_{1,FW}} - \frac{1}{\tau_{FW}} \end{bmatrix}$$

where ϕ is the RF pulse phase, $\Delta\omega$ is the off-resonance frequency, f is the volume fraction, τ is the proton residence time and *MW* and *FW* denote the myelin and free water pools, respectively. Under usual conditions the off-resonance value is assumed negligible, $\Delta\omega = \Delta\omega_{MW} = \Delta\omega_{FW} = 0$. However, in areas of steep susceptibility-induced gradients, such as the sinuses, this assumption is no longer appropriate. Provided sufficient data is available, $\Delta\omega$ may be included as an additional free parameter in the fitting routine. A 7-parameter fit within the low signal artifact areas, however, is ill-posed. To account for this, we make use of RF phase-cycling, which shifts the spatial location of the artifact, and acquire a second set of multi-angle SSFP data. Combined, this data provides high signal in all image areas, allowing us to calculate artifact free maps. To demonstrate the technique *in vivo*, mcDESPOT data were acquired with the following parameters: SPGR: TE/TR=2.4/6.7ms, α={2,3,4,5,6,7,9,13,18}°. BW=±19.3kHz, SSFP: TE/TR=1.7/3.8ms, α={11,16,22,27,34,41,51,67}°, ϕ={0, 180}°, *BW*=±50kHz, A 22cmx22cmx15cm Sagittal *FOV,* 128x128x90 matrix (zero-padded to 128x128x90) for a total acquisition time of approx. 15 minutes. Using a stochastic region contraction fitting approach[2], the 7-parameter fit of the SPGR and SSFP signal models were calculated. For comparison, the data were also analyzed assuming $\Delta\omega = 0$.

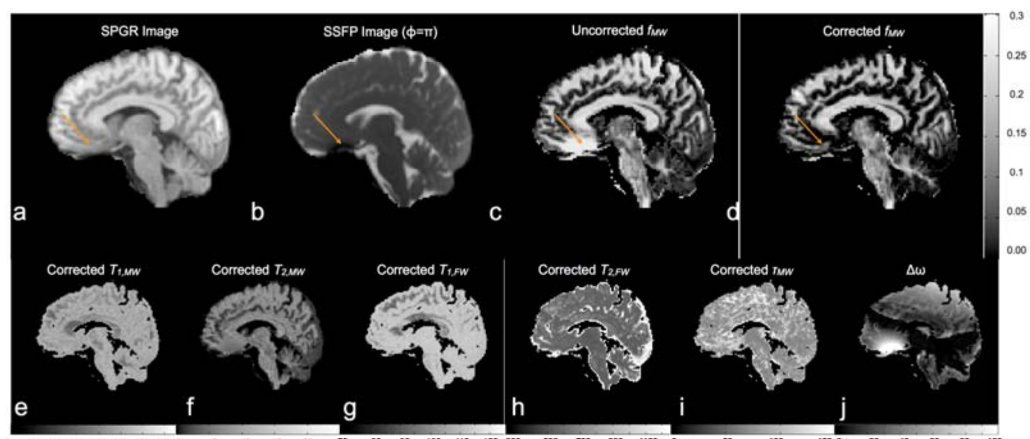

Figure 2: Representative slices through reference SPGR (a), SSFP (b) and corrected and uncorrected mcDESPOT parameter maps. Obvious artifact is observed within the uncorrected myelin water fraction map (c) corresponding to the large off-resonance demonstrated in the Δω map (j). The corrected myelin fraction map (d) shows complete removal of this artifact and no other remnants are observed in the other mcDESPOT derived parametes (e-i).

RESULTS / DISCUSSION: Representative sagittal slices through the heavily affected brain region immediately superior to the sinuses are shown in Fig. 2. Whilst substantial artifact is observed in the uncorrected $\Delta\omega = 0$ volume fraction map, complete removal of the artifact is observed in the 7-parameter fit results. Fig. 2 also demonstrates not only the disperse impact of the off-resonance artifact on the myelin fraction map, but also degree of off-resonance throughout the brain. Despite the lack of obvious artifact, significant off-resonance is observed throughout the brain and leads to a general over-estimation of myelin water volume fraction. Though the acquisition of an additional SSFP dataset increases the overall acquisition time, the 15 minute scan time reported herein remains clinically feasible.

REFERENCES: [1] Deoni SCL. et al. Magn. Reson. Med.*In Press*. [2] Berger MF, Silverman HF. IEEE Trans. Signal. Proc. 1991; 39: 2377-2386.