Artifacts in T1ρ-weighted Imaging: Compensation for B0 and B1 Field Imperfections

W. R. Witschey[1], A. Borthakur[2], M. A. Elliott[2], S. Niyogi[3], C. Wang[3], D. J. Wallman[4], and R. Reddy[2]

[1]Biochemistry & Molecular Biophysics, University of Pennsylvania, Philadelphia, PA, United States, [2]Radiology, University of Pennsylvania, Philadelphia, PA, United States, [3]Bioengineering, University of Pennsylvania, Philadelphia, PA, [4]Radiology, University of Pennsylvania, Philadelphia, PA

Introduction: T1ρ-weighted contrast is an emerging MR contrast type sensitive to changes during osteoarthritis, cerebral ischemia (4) and metabolic $H_2{}^{17}O$ (2), but is confounded by image artifacts. The origin of T1ρ-weighted image artifacts in the presence of B_0 and B_1 magnetic field imperfections is derived using the Bloch equations and demonstrated experimentally at low ($\omega_1 << \Delta\omega_0$), intermediate ($\omega_1 \sim \Delta\omega_0$) and high ($\omega_1 >> \Delta\omega_0$) spin locking field strengths. At low spin locking fields, the magnetization is shown to oscillate around an effective field in the rotating frame causing signature banding artifacts in the image. At high spin lock fields, the effect of the resonance offset $\Delta\omega_0$ is quenched, but imperfections in the flip angle cause oscillations about the ω_1 field. A pulse sequence based on integrated spin echo and rotary echo spin lock experiment (1,5) followed by magnetization storage along the -z-axis. The sequence was used to obtain artifact free images of agarose in inhomogeneous B_0 and B_1 fields, off-resonance spins in fat and *in vivo* human brain.

Methods: Imaging was performed on a Siemens Trio 3T clinical imaging system equipped with a Bruker birdcage head coil. Volunteers were recruited to the study and scanned following a pre-approved protocol by the IRB of the University of Pennsylvania. Imaging was performed using variations of a T1ρ-prepared fast spin echo sequence with the following imaging parameters (TE_{eff}/TR = 13/2500 ms, 128x128 image matrix, FOV = 23 cm^2, slice thickness = 4 mm, ETL = 7, BW = 130 Hz/pixel. Agarose (3% w/v, 200 mM ^{23}Na) or water/fat phantom (150 mL mineral oil/ 200 mL doped H_2O) imaging was performed using a similar protocol (FOV = 15 cm^2). Four spin lock variants were chosen to examine image artifacts (Fig. 3) and consist of both rotary echo, spin echo, and storage phase inversion components. T1ρ-preparation was performed using variations of a conventional spin lock pulse clusters with either a rotary echo, spin echo, phase inversion (Fig. 3). A B_0 field map was obtained from four complex gradient echo images (TE = 5, 7.5, 10 and 15 ms) and phase unwrapped using a program written in IDL. B_1 field maps were obtained using a B_1 field mapping protocol (5). Briefly, magnetization is excited with incremental pulse flip duration (τ = 150, 200, 250, 300, 350 μs) followed by a gradient crusher and fast spin echo acquisition. Post-processing of both the ΔB_0 and B_1 field maps involved zeroing non-finite pixel values, 3x3 boxcar smoothing filter and a binary mask of linear fits with $R^2 < 0.995$.

Results: Results of four spin lock pulse cluster variants were simulated from B_1 and B_0 fieldmaps using the Bloch equations and shown alongside actual T1ρ-weighted images (Fig. 1). The results of the simulation demonstrate that ΔB_0 is the primary cause of artifacts at low spin lock amplitude ($\omega_1 << \Delta\omega$) and B_1 inhomogeneity at high ($\omega_1 >> \Delta\omega$) amplitude. To illustrate full ΔB_0 insensitivity during spin locking,, a fat/water phantom was imaged using the four sequence variants (Fig. 2). Notably, the sequence variants have a substantial effect on image contrast between spins on and off-resonance (CNR = 11:1 and 60:1, Fig. 2, 2 rightmost images). At 3T and ω_1 = 500 Hz, the ω_{eff} makes an angle $\varphi \approx 51°$ to the z-axis and produces severe banding artifacts in both conventional and B_1 insensitive T1ρ-weighted imaging. The artifact is removed in ΔB0 or ΔB0 and B1 insensitive pulse clusters. T1ρ-weighted images were obtained of the human brain *in vivo* and show significant $\Delta\omega_0$ banding artifacts at low spin lock amplitudes ($\omega_1 \sim \Delta\omega_0$), which are also eliminated with the new sequence (Fig. 3).

References: 1. Avison M, et al. A Composite Spin-Lock Pulse for deltaB0 + B1 Insensitive T1rho Measurement. 2006; ISMRM Seattle, WA. 2. Tailor DR, et al. Magn Reson Med 2003;49(3):479-487. 3. Redfield AG. Physical Review 1955;98(6):1787-1809. 4. Grohn OH, et al. Magn Reson Med 2003;49(1):172-176. 5. Charagundla SR, et al. JMR. 2003;162(1):113-121. Regatte RR, et al.. Radiology 2003;229(1):269-274. Regatte RR, et a; .Acad. Radiol 2004;11(7):741-749.

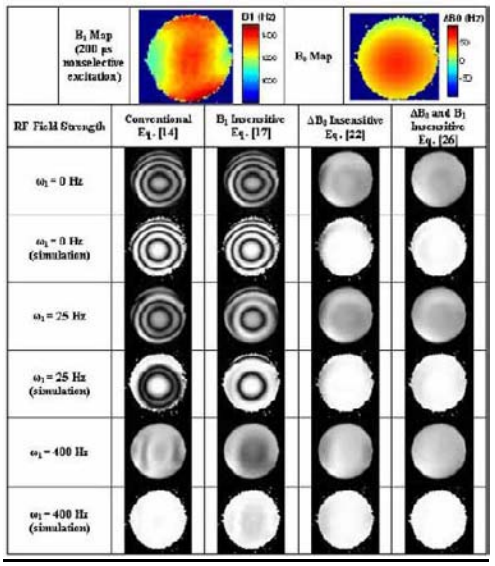

Fig. 1: Simulated and actual spin lock artifacts at TSL = 30 ms, ignoring relaxation effect in 3 different ω1 regimes: (1) $\Delta\omega >> \omega1$ ($\omega1$ = 0 Hz) (2) $\Delta\omega \sim \omega1$ ($\omega1$ = 25 Hz) and (3) $\Delta\omega << \omega1$ ($\omega1$ = 400 Hz). Field maps reflect automatic pulse calibration and shim delivered at a nominal B1 = 1250 Hz and ΔB0 = 0 Hz.

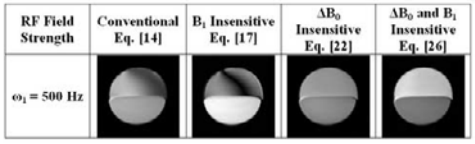

Fig. 2: T1ρ-weighted imaging of a water and fat phantom. Off-resonance fat protons nutate about an effective field in the rotating frame. This nutation causes a spin-lock duration and amplitude (ω_{eff}TSL) dependent artifact in conventional and B1 insensitive T1ρ-weighted imaging, but is absent in ΔB0 insensitive methods, which restore magnetization to their prior orientation.

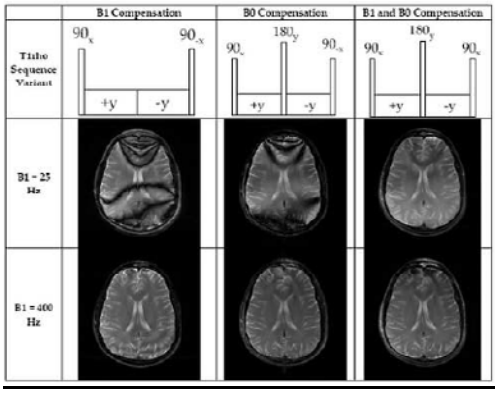

Fig. 3: T1ρ-weighted imaging of the brain at 3T. Low spin lock amplitudes (ω1 = 25 Hz) induce Δω0 banding artifacts in both B1 compensation and B0 compensation sequence variants.