Quantitative T1rho Imaging Using Phase Cycling For B0 and B1 Field Inhomogeneity Compensation

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Introduction: T1rho imaging is promising in a number of clinical applications, such as early detection of osteoarthritis. T1rho imaging, however, is sensitive to B0 and B1 inhomogeneities (1-3). In this work, we present a phase cycling method to eliminate B1 inhomogeneity effects in T1rho imaging. The presence of B0 field non-uniformity can compromise B1 inhomogeneity compensation approaches. We present a method which combines the phase cycling approach with a composite RF pulse scheme proposed by Dixon et al (2) for simultaneous compensation of B0 and B1 inhomogeneity in T1rho imaging. The proposed T1rho RF preparation methods can be combined with an SNR-efficient 3D T1rho imaging method MAPSS (4) without compromising scan time.

Theory: *B1 inhomogeneity compensation:* The "rotary echo" method proposed by Charagundla et al (1), where the phase of the spin-locking RF pulse is alternated for the second half of the pulse, is commonly used to address B1 inhomogeneity in T1rho imaging. This method reduces banding artifacts, but T2rho contamination caused by B1 inhomogeneity remains, which can result in T1rho quantification errors. Here we present a phase cycling method as shown in Figure 1a to address this problem. We alternate the sign of the phase of the tip-up RF pulse (pulse 3 in Figure 1a) in the T1rho preparatory RF pulse cluster. The final image is the subtraction of the acquired two images (5,6). This phase cycling approach results in T1rho-prepared signal consisting of T1rho relaxation term with only a constant scaling, therefore it can eliminate both banding artifacts and T2rho contamination and achieve accurate T1rho quantification. Figure 2 shows a Bloch simulation of Charagundla's method and the phase cycling method when the actual B1 field is 60% of the expected B1 field. Note the phase cycling method can track the actual T1rho relaxation whereas Charagundla's method shows errors due to T2rho contamination.

B1 and B0 inhomogeneity compensation: The presence of B0 field inhomogeneity can compromise B1 inhomogeneity compensation approaches in T1rho imaging. Witschey et al has reported a method which combines the rotary echo method with a refocusing RF pulse for simultaneous correction of B1 and B0 field inhomogeneity (3). We propose to address this problem by combining phase cycling with a composite RF pulse scheme proposed by Dixon et al (2), as shown in Figure 1b. We term this method Phase-Cycled Composite Spin-Lock (PCC-SL). Figure 3 shows Bloch simulation of four different methods when there is 80 Hz B0 inhomogeneity and the actual B1 value is 80% of the expected B1 value. Note the presence of B0 and B1 inhomogeneity induces signal oscillation while PCC-SL achieves reduced oscillation compared to the other methods.

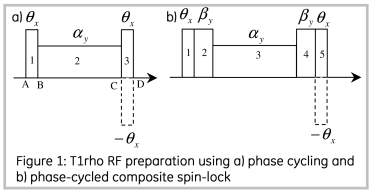

Figure 1: T1rho RF preparation using a) phase cycling and b) phase-cycled composite spin-lock

Method and Results: Data sets were collected from a 3T GE Signa scanner (GE Healthcare, Waukesha, WI) using a transmit-receive 8-ch knee coil (Invivo Inc., Gainesville, FL). A spin-warp sequence was used to collect data after T1rho preparation for all methods. Data sets were collected at four TSLs, 0, 20, 40, and 60ms, and at a spin lock frequency of 500 Hz. Other pulse sequence parameters: FOV 16x12 cm, TR/TE 600/10ms, matrix 256x160, flip angle 90 degree, slice thickness 5mm, BW±31.25kHz (for phantom) and ±61.25kHz (for in-vivo), and 2 averages. The total scan time is 12 min for all the methods.

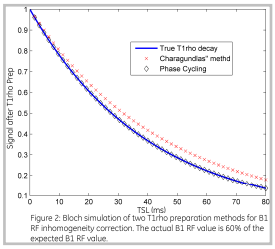

Figure 2: Bloch simulation of two T1rho preparation methods for B1 RF inhomogeneity correction. The actual B1 RF value is 60% of the expected B1 RF value.

For phantom studies, six T1rho preparation approaches were compared, including: conventional method without B1 and B0 inhomogeneity compensation, Charagundla's method, Dixon's method, Witschey's method, phase cycling, and PCC-SL. Figure 4 shows phantom example images collected at TSL=60ms and the corresponding measured T1rho map. Images acquired from both Dixon's and Charagundla's methods show obvious banding artifacts, indicating non-uniformity of both B0 and B1 field. Witschey's method demonstrates improved image quality, but banding artifacts are still observed near the edge where field inhomogeneities are more pronounced. PCC-SL achieves further reduction of banding artifacts compared to the other studied methods. Banding artifacts are also apparent in the calculated T1rho maps, indicating likely errors in the T1rho values at these areas.

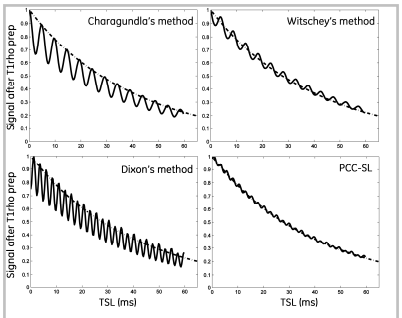

Figure 3: Bloch simulation of four T1rho preparation methods for B0 and B1 inhomogeneity correction. The actual B1 RF value is 80% of the expected B1 RF value and B0 is 80Hz off-resoance. The dashed lines are the actual T1rho decay curve and the solid lines are the simulated signal from four T1rho preparation methods.

Figure 5 and 6 show an in-vivo example. The center frequency was intentionally changed by 50 Hz to increase B0 field inhomogeneity for this study. No fat suppression was applied. Note banding artifacts in subcutaneous fat was significantly reduced using PCC-SL. The differences between the T1rho maps acquired using the rotary echo method and PCC-SL can result from B1 and B0 inhomogeneities around cartilage. It is also possible that slight volunteer motion during these long scans may have also contributed to these differences.

Discussion: 3D T1rho imaging is desirable for high-resolution clinical applications. Conventional 3D T1rho imaging methods suffer from intensive SAR (T1rho prep is played out each TR) and SNR inefficiency. MAPSS (4) is a 3D T1rho imaging method which addresses this problem by acquiring transient signal during the approach to steady state. The same phase cycling reported in this work is implemented in MAPSS to remove T1 relaxation effect during signal evolution. Therefore, the proposed methods can be combined with MAPSS for improved 3D T1rho imaging without compromising scan efficiency.

SAR is a major limiting factor for in-vivo T1rho imaging. This problem can be especially pronounced when using a body coil for RF transmission and long TSL spin lock pulses, as may be required for T1rho imaging of the spine. One potential solution to the SAR challenge is to use local transmit surface coils. Phase cycled spin lock approaches remove B1 inhomogeneity induced T1rho quantification errors which may enable the use of local transmit surface coils for T1rho imaging.

Conclusion: T1rho imaging is sensitive to B0 and B1 inhomogeneities. We present a phase cycling approach which eliminates B1 RF inhomogeneity effects in T1rho imaging. By combining this method with the spin-locking method proposed by Dixon et al (2), we achieve simultaneous compensation for effects caused by B0 and B1 inhomogeneities in T1rho imaging.

Reference: 1. Charagundla et al, JMR 2003 p113; 2. Dixon et al, MRM 1996, p90; 3. Witschey et al JMR 2007 p75; 4. Li et al, MRM 2008 p298; 5. Wright et al Proc ISMRM 1996, p1474; 6. Li et al, MRM 2006 p929

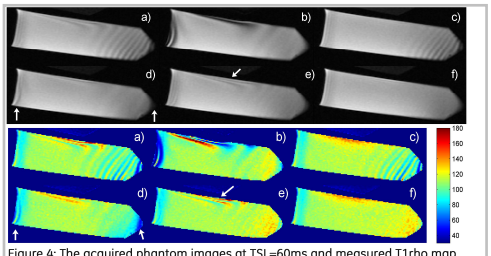

Figure 4: The acquired phantom images at TSL=60ms and measured T1rho map using a) No correction,b) Charagundla's method, c) Dixon's method, d) Witschey's method, e) Phase cycling method, and f) PCC-SL The white arrows indicate where there are banding artifacts in T1rho-weighted images and likely errors in T1rho map.

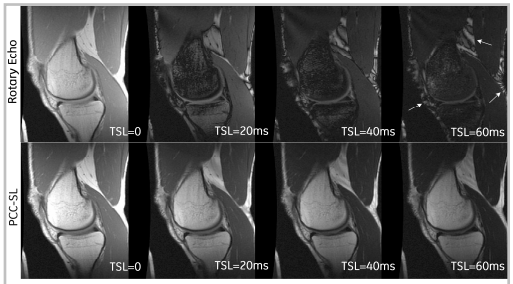

Figure 5: T1rho-weighted images acquired using Charagundla's method and PCC-SL at four different TSLs. White arrows indicate banding artficats in subcutaneous fat.

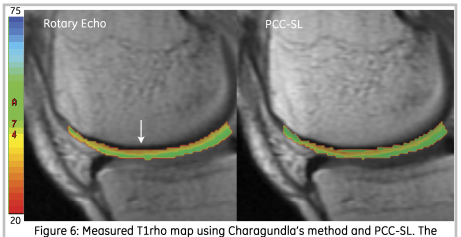

Figure 6: Measured T1rho map using Charagundla's method and PCC-SL. The white arrow indicates the area where T1rho map show reduced value in that acquired using Charagundla's method but not in that acquired using PCC-SL.