Pseudo steady state fast spin echo acquisition for quantitative 3D T1rho imaging

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Introduction: T1rho imaging is promising in a number of clinical applications. Most current T1rho imaging methods are based on 2D acquisitions; however, 3D imaging is clinically preferred in order to achieve full volume coverage and higher spatial resolution. A few 3D T1rho imaging methods have been reported (1-3). The 3D SPGR based method (1) suffers from long scan time and may require a prior knowledge of T1 value for T1rho quantification. 3D T1rho imaging using transient signal in balanced-SSFP acquisition can significantly reduce scan time (2). However, T1 relaxation and signal modulation during transient stage may result in quantification errors and a prior knowledge of tissue properties, including T1 and T2, are needed for correction of these errors. MAPSS (3) is a 3D T1rho imaging method that acquires SPGR signal during the approach to steady state. A phase cycling approach is employed in MAPSS to eliminate T1 relaxation effect, which prolongs scan time. For MAPSS application, a T1 value is usually assumed to correct signal modulation caused by transient signal evolution.

Fast-spin-echo (FSE) (4) plays a central role in clinical MRI. Conventional FSE sequences are limited in scan efficiency due to T2 relaxation-induced blurring and SAR intensity. Recent advances have greatly reduced scan time and SAR intensity in 3D FSE imaging by using very long echo train through refocusing flip angle modulation (5-8). Here we demonstrate the feasibility of this approach for SNR-efficient fast quantitative 3D T1rho imaging. Unlike other 3D T1rho imaging methods, the proposed approach does not require a prior knowledge of tissue properties, such as T1 or T2 value.

Theory and Methods: The pulse sequence starts with T1rho preparation, followed by the pseudo-steady-state fast 3D FSE approach described in (8). After each echo train, a magnetization-reset module (3) is applied to maintain consistent initial magnetization prior to the next T1rho preparation.

Accurate T1rho quantification using this data acquisition approach requires that the effect of T1 recovery on signal during very long echo train readout be negligible. Otherwise, the point spread function may depend on the initial magnetization after T1rho preparation. This effect would violate the assumption that image intensity from different TSLs is a function only of T1rho exponential decay. Because refocusing pulses less than 180° are used, signal decay is influenced by both T1 and T2 (due to mixing of spin and stimulated echo signal components). However, when the CPMG condition is met and the crusher gradient is sufficient so that FID is eliminated, T1 recovery during the readout is eliminated. The point spread function for all TSL values is identical and relative image intensity between images acquired with different TSL values depends only on T1rho exponential decay during spin lock. Figure 1 shows the simulation results using Extended Phase Graph (EPG) algorithm and Bloch simulation, demonstrating the need to meet the FID crusher requirements.

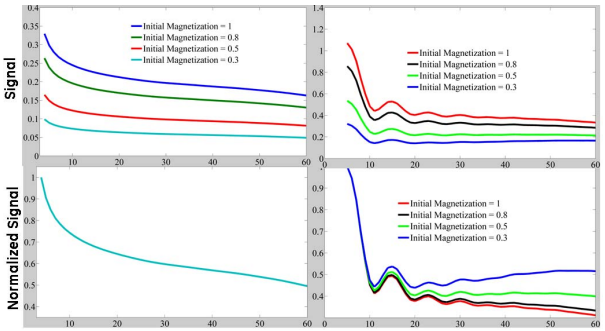


Figure 1: Simulated signal profiles during echo train in the PSS fast spin-echo imaging method with different initial magnetization (0.3, 0.5, 0.8, 1) before 90 degree RF excitation; a) using EPG algorithm; b) using Bloch simulation of 1 million spins with insufficient crusher gradient. After being normalized by the signal at the beginning of individual echo train, c) the signal profiles shown in a) overlap with each other, whereas d) the signal profiles shown in b) do not overlap with each other.

The data sets were collected from a 1.5T Signa HDx scanner (GE Healthcare, Waukesha, WI) using a transmit-receive 8-channel knee coil (Invivo Inc., Gainesville, FL). The imaging parameters include: spin-lock frequency 500Hz, TR (excluding T1rho preparation time) 2.1sec, TE 17.2ms, BW±62.5kHz, FOV 14x12.6cm, acquisition matrix 256x256 (in plane resolution 0.55x0.55mm), 36 slices with slice thickness 3mm, and echo train length (ETL) 60. Four TSLs were acquired at 1, 20, 40, and 60ms. A data-driven auto-calibrating parallel imaging method, ARC (9,10), along phase encoding direction (net acceleration 1.69) combined with partial Fourier acquisition was applied. The total acquisition time was 5:18.

Results and Discussion: The scan time is significantly shorter than other 3D T1rho imaging methods with same volume coverage and spatial resolution. In-vivo studies show the proposed method can achieve high SNR efficiency for 3D T1rho imaging, as can be seen from Figure 2 which is one slice of a 3D T1rho-weighted volunteer dataset. Figure 3 shows the estimated T1rho map at the same slice. The measured T1rho value in cartilage is consistent with other published results. The plot in Figure 3 shows that the magnitude images acquired at 4 TSLs from a single pixel on tibial cartilage (red cross) follow an exponential fitting curve (blue line).

Current studies were conducted at 1.5T. One of the current developments is to implement the pulse sequence for 3T imaging. The higher SNR at 3T may enable even higher resolution or further acceleration of data acquisition. A moderate ETL (60) is used here for knee MRI due to relative short T2 of cartilage. For applications with longer T2, such as brain imaging, we can use much longer ETL, which can significantly reduce scan time. Besides T1rho mapping, this pulse sequence may also be applied for 3D parametric imaging of other tissue properties, such as T2 mapping.

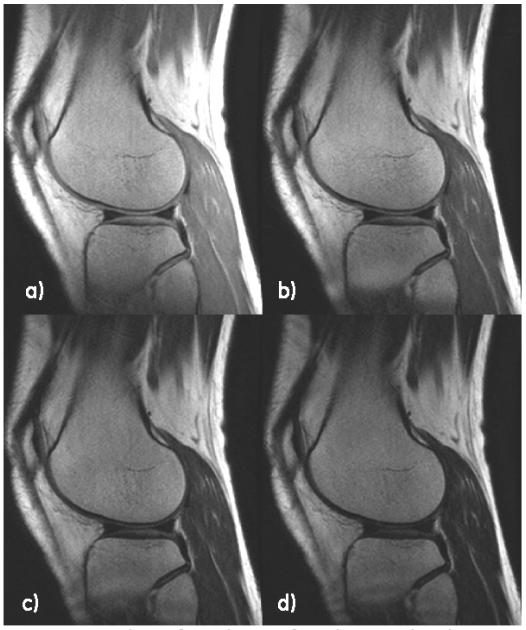
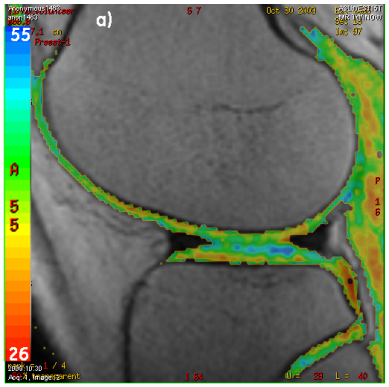


Figure 2: One slice of a volume of T1rho-weighted images from a volunteer scan using the reported 3D T1rho imaging method. Four images are acquired at TSL equal to: a) 1ms, b) 20ms, c) 40ms, and d) 60ms.

It is important to keep CMPG condition for the reported approach so that T1 relaxation effect does not take place during long echo train readout. Care should be used when CPMG condition is violated under certain circumstances, such as the case when the phase error of refocusing RF pulses is induced by eddy current effect. The robustness of the proposed method for routine clinical assessment is under further investigation.

Conclusion: We reported a 3D T1rho imaging approach based on pseudo steady state fast spin-echo acquisition. This approach does not require a prior knowledge of tissue properties. In-vivo studies show that the proposed method can achieve high scan and SNR efficiency for 3D quantitative T1rho imaging.

Reference: 1. Borthakur et al, JMRI 2003, p730 2. Witschey et al, JMRI 2008 p744 3. Li et al, MRM 2008 p298 4. Hennig et al JMR 1988 p397 5. Mugler et al, ISMRM 2000 p687 6. Hennig et al, MRM 2004 p68 7. Busse et al, MRM 2006 p1030 8. Busse et al, MRM 2008 p640 9. Beatty et al, ISMRM 2007, p1749 10. Brau et al, MRM 2008, p382



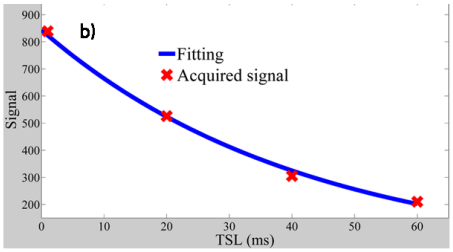


Figure 3) a) T1rho map calculated from the images shown in Figure 2. b) Image intensity of a single pixel from tibial cartilage acquired at 4 TSLs follows an exponential fitting.