UTE 3D Cones Trajectory with T1ρ weighted imaging for MSK applications

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Introduction

$T_{1\rho}$ has been identified as a novel biomarker which is useful to identify precursors of osteoarthritis, such as loss of proteoglycans [2,3]. However, regular $T_{1\rho}$ sequences cannot easily access tissues or tissue components with relatively short T2s (e.g., the deep layers of articular cartilage, meniscus, ligaments, tendons, etc). The combination of 2D ultrashort echo time (UTE) sequence with spin-lock preparation has allowed $T_{1\rho}$ contrast to be visualized for both short and long T2 tissues in the musculoskeletal (MSK) system [1]. However, the 2D UTE-$T_{1\rho}$ sequence suffers from low SNR inefficiency, eddy currents, and poor slice coverage. 3D $T_{1\rho}$ sequences are now being developed to avoid the complications of 2D sequences[5]. To address these issues we have implemented a self-compensated $T_{1\rho}$ preparation with a SNR efficient 3D Cones sequence to provide image quality with a reasonable imaging scan time using a clinical 3T scanner [4].

Methods

All scans were performed on a 3T Signa TwinSpeed scanner (GE Healthcare Technologies, Milwaukee, WI). The sequence consisted of a 3D Cones [4] sequence preceded by a self-compensated spin-lock preparation pulse [3], as shown in Figure 1. During the spin lock time (TSL) T1ρ contrast is developed. A $CuSO_4$ spherical ball phantom was used for comparison of 2D spiral-$T_{1\rho}$ and and 3D Cones-$T_{1\rho}$ sequences. The 3D Cones-$T_{1\rho}$ imaging parameters were as follows: TR=160ms, matrix=192×192×30, TE=32µs, FA=16°, FOV=16cm for phantom and volunteers, and 4 cm for meniscus samples, slice thickness = 3 mm (1 mm for meniscus), spin-locking field = 500 Hz, TSL=0.02/5/10/20 ms. For none fat-sat imaging the scan time is 15 min per TSL. For fat-sat imaging five cones trajectories were sampled with each fat sat and spin-locking preparation pulse, and the scan time was reduced to 3 min per TSL. For 2D spiral- $T_{1\rho}$, similar imaging parameters were used with a total scan time of 6 min. T1 effects were minimized by measuring T1 with a variable TR 3D Cones approach and in corporating T1 into the fitting of $T_{1\rho}$. The 2D spiral-$T_{1\rho}$ and 3D Cones-$T_{1\rho}$ without and with fat sat were applied to phantom and bovine meniscus samples (n=5). Only the 2D spiral-$T_{1\rho}$ and the 3D Cones-$T_{1\rho}$ with fat sat were applied to healthy human volunteers (n=5) to save scan time. An 8-channel knee coil was used for phantom and in vivo studies. A solenoid coil was used for meniscus sample study.

Results and Discussion

There was close agreement between the phantom $T_{1\rho}$ values obtained from 2D spiral-$T_{1\rho}$ and 3D Cones-$T_{1\rho}$ sequences (**Figure 2**). The slightly greater $T_{1\rho}$ values with the 3D cones-$T_{1\rho}$ sequence as compared to the 2D spiral-$T_{1\rho}$ sequence may be attributed to the greater T1 saturation in the former which had a much shorter TR. Further T1 compensation may be needed.

Figure 3 shows 3D Cones-$T_{1\rho}$ imaging of a bovine meniscus and $T_{1\rho}$ fitting with different approaches. 3D Cones-$T_{1\rho}$ shows slightly lower value than spiral-$T_{1\rho}$ probably due to the contribution of the shorter T2 components in the meniscus, which cannot be detected with the spiral-$T_{1\rho}$ sequence.

Figure 4 shows 3D cones-$T_{1\rho}$ imaging of a 28 year old healthy volunteer. Tibial plateau shows a $T_{1\rho}$ of 36 ms, which is consistent with literature values. The meniscus showed a relatively long $T_{1\rho}$ of 18 ms.

Conclusion

The self-compensated spin lock preparation pulse preceding the 3D Cones-$T_{1\rho}$ sequence provides a novel SNR efficient method to obtain volumetric $T_{1\rho}$ contrast, and consistent values of $T_{1\rho}$ appropriate for clinically relevant MSK applications (including short T2 tissues such as meniscus).

References

[1] X. Li et al, Osteoarthritis Cartilage 2007. [2] J. Du et al MRM 64:834–842 (2010) [3] A. Borthakur et al. JMR 167 (2004) 306–316 [4] P.T. Gurney et al MRM 55:575–582 (2006), [5] X Li et al. MRM 59(2): 298–307(2008).
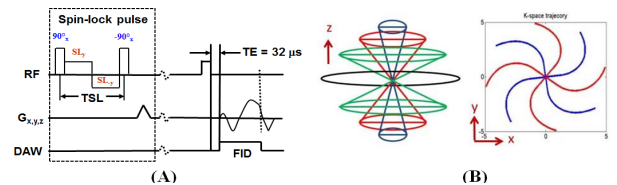
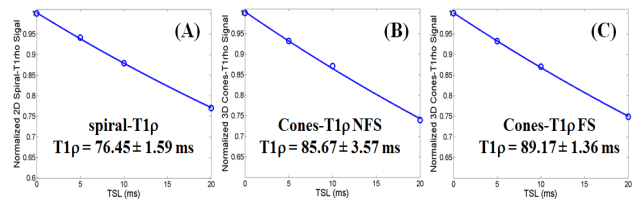Figure 1: T1ρ prepared 3D Cones sequence A) pulse sequence timing diagram, B) k-space trajectory
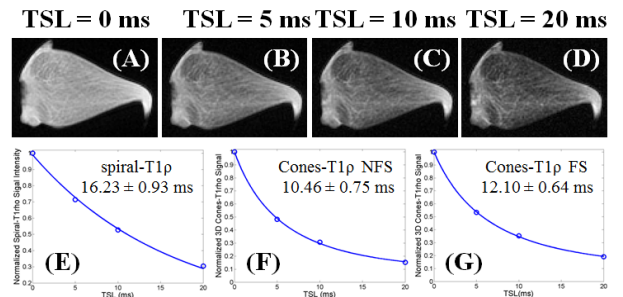

Figure 2: CuSO4 Ball phantom T1ρ values

Figure 3: Ex-vivo 3D Cones images with Spin-Lock Time (TSL) of 0, 5, 10, 20 ms (A-D) of human meniscus samples. Comparison to 2D spiral-T1ρ (E), 3D cones-T1ρ with NFS (F) and with FS(G).
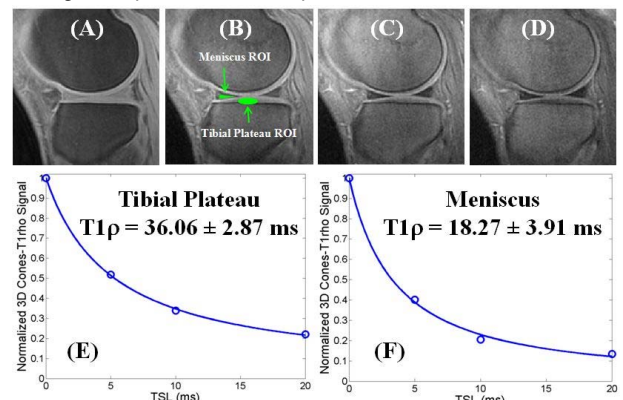

Figure 4: In vivo 3D Cones-T1ρ images with TSL of 0.02, 5, 10 and 20 ms (A-D) of the knee joint of a 28 year old healthy volunteer. ROI analysis is shown for Tibila Plateau (E) and meniscus (F).