A New 3D Isotropic $T_{1\rho}$ Mapping Technique for *In Vivo* Human Knee Cartilage at 7T MRI

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Introduction: Osteoarthritis (OA) is a degenerative disease affecting Articular Cartilage (AC) of synovial joints in shoulders, knee, hip, etc. It is reported that ~5% of the population over 25 years of age and ~12% over 60 years of age are diagnosed with knee OA[1]. Spin-lattice relaxation in the rotating frame ($T_{1\rho}$) has been a promising quantitative MRI imaging technique to diagnose OA at an early stage by detecting changes in the proteoglycan and collagen matrix in the cartilage[2]. High resolution MRI is desired across the thickness of AC (which varies from 1-6 mm) particularly in OA patients to identify the extent of the cartilage degeneration. With current methods, due to the practical scan time considerations, two 2D/3D scans in axial and coronal/sagittal orientations are performed for patellar and femoral/tibial cartilages respectively with <1mm in-plane resolution and 3-5 mm slice thickness[3, 4]. Here we propose a new 3D-GRE based time efficient method to acquire $T_{1\rho}$ weighted images of the whole knee at an isotropic resolution (0.5 mm^3) within 12 min scan time that allows reformatting of the isotropic images of knee to any desired orientation with $T_{1\rho}$ maps calculated for patellar, femoral and tibial cartilages and validated the proposed method with existing technique.

Materials and Methods: All the human studies were conducted under an approved Institutional Review Board protocol of the University of Pennsylvania. Seven healthy volunteers of age 32.8 ± 14 years underwent MRI at whole body 7T scanner (Siemens Healthcare, Erlangen, Germany) using a 28-channel Knee Coil (Quality Electrodynamics, OH, USA). A new 3D $T_{1\rho}$ sequence has been developed as shown in Fig 1. Readout is done with very low flip (~5°) angle spoiled gradient echo segments (~600 echo segments per shot with a GRAPPA factor of 2 along phase encoding direction) to obtain rapid 3D images with 30 shots of TR 6s each. Using this 'burst mode' shot strategy, a high throughput rate (>80%) for readout is achieved. Spin-lock pulse amplitude was kept constant at B_1 = 500Hz for various spin lock times, TSL = 0, 14, 28 and 42 ms with TR/TE = 8.7/3.32 ms and NEX = 1, FOV = 160×160×80 mm^3, matrix size = 320×320×160 with 0.5 mm^3 isotropic resolution in axial orientation. Total acquisition time was 12 min. In addition, $T_{1\rho}$ weighted images in axial and coronal orientations were acquired in 0.5×0.5×3 mm^3 resolution for the comparison of $T_{1\rho}$ maps with the proposed technique. The data corresponding to different TSLs were fitted to a mono-exponential decay expression $S(TSL) = (M_0 - M_{zss}) \times e^{(-TSL/T1\rho)} + M_{zss}$ to generate $T_{1\rho}$ maps, where '*TSL*' is the spin lock time in 'ms', 'M_0' is the thermal equilibrium and 'M_{zss}' is the steady-state *Z* component of magnetization. The images of isotropic resolution were reformatted to 0.5×0.5×3 mm^3 slices in axial and coronal orientations to compare the results with non-isotropic acquisitions.

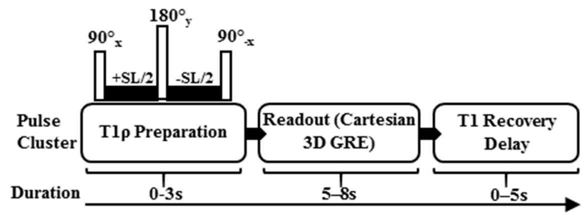

Fig 1 The preparation block consists of a Spin lock preparation[5] for $T_{1\rho}$ measurements followed by 3D GRE readout to spatially encode the signal and a delay block to allow T1 recovery

Results: Axial $T_{1\rho}$ maps of a healthy volunteer obtained from the proposed technique and reformatted to coronal and sagittal orientations are shown in Fig 2. $T_{1\rho}$ values of knee cartilages calculated using the proposed method in isotropic resolution (center slice) and reformatted to 3 mm thick slices are shown in Fig 3A (patellar, 0.5 mm center slice / 3mm reformatted: 34.36±4.0 / 32.66±4.0 ms; femoral: 44.6±2.0 / 43.38±1.3 ms and tibial: 39.71±4.1 / 38.28±3.3 ms). Accuracy of the proposed approach was validated by reformatting the isotropic images to axial and coronal orientations to 3mm thick slices and the $T_{1\rho}$ values of each cartilage are compared with the $T_{1\rho}$ values obtained from acquisitions with conventional non-isotropic technique (we noticed 2.3 , 9.8 , 10.9 % difference in patellar, femoral and tibial cartilages respectively) which is shown in Fig 3B. Fig 4 shows an example of a $T_{1\rho}$ map of the patellar cartilage of a healthy volunteer in isotropic resolution, reformatted to a 3 mm thick slice and the corresponding 3mm slice acquired slice using the non-isotropic acquisition method. It can be seen that the $T_{1\rho}$ values are higher in superficial region and reducing in the deeper regions.

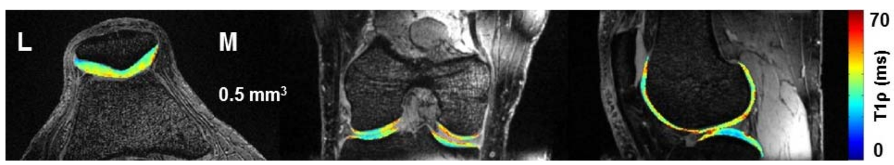

Fig 2 Axial, reformatted - coronal and sagittal sections of the healthy knee showing $T_{1\rho}$ maps acquired using 3D isotropic MRI.

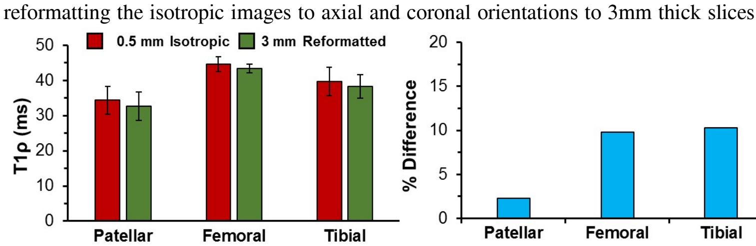

Fig 3 A. $T_{1\rho}$ values of cartilages calculated from images acquired at isotropic resolution (center slice) and reformatted to 3mm thick slices. B. % change in $T_{1\rho}$ values calculated from isotropic acquisition with non-isotropic acquisition.

Discussion: Recently, there has been interest in musculoskeletal imaging at isotropic resolution due to the complexity of the anatomy and size of the structures. To the best of our knowledge this is the first study reporting 0.5 mm^3 isotropic $T_{1\rho}$ imaging results at 7T. We developed a highly efficient and rapid isotropic sequence to acquire $T_{1\rho}$-weighted images and quantitatively validated the accuracy of the $T_{1\rho}$ values calculated. Since AC of knee is a curved surface, the proposed isotropic $T_{1\rho}$ imaging may improve the diagnostic accuracy particularly in OA patients at a practically achievable scan time. Work is in progress to evaluate the reason for the deviation of $T_{1\rho}$ values in femoral and tibial cartilages from the conventional method and validate this technique with additional healthy volunteers of different age groups and subjects with knee pain.

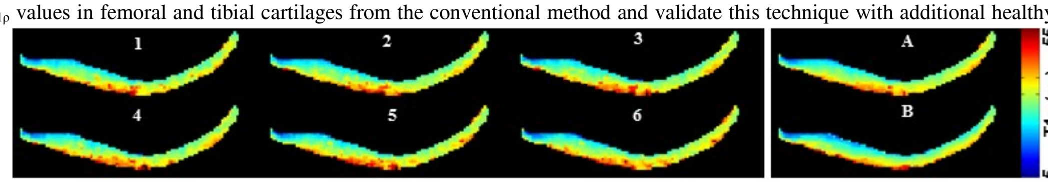

Fig 4 $T_{1\rho}$ map of segmented patellar cartilage in axial view, 1 to 6 shows slices with isotropic resolution, **A** reformatted slice by combining 1 to 6 and **B** $T_{1\rho}$ map calculated from $T_{1\rho}$ weighted image acquired with 3mm slice thickness

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