

## Reproducibility of High-Resolution T1ρ Mapping of Human Knee Cartilage at 7T

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**Purpose:** The objective of this study was to evaluate the reproducibility of high resolution (in plane resolution = ~0.2 mm<sup>2</sup>) T1ρ maps of human-knee cartilage at whole body 7T MR scanner. T1ρ measurements have been used to evaluate the macromolecular content of cartilage at clinical MR field strengths (1.5T and 3T)<sup>1-3,5</sup>. While imaging of knee cartilage at ultra high field may have advantages in term of SNR, reliability of T1ρ measurements has not yet been assessed. In this study we performed high resolution T1ρ mapping in knee cartilage of healthy subjects and tested reproducibility of T1ρ maps by computing coefficient of variation and intraclass correlation coefficient.

**Materials and Methods:** Ten healthy volunteers (20-64 yrs) participated in this study under an approved institutional review board protocol and informed consent was obtained from each one before scanning on a 7T whole body MRI scanner using a 28ch knee coil. In order to determine reproducibility, subjects either had one or both knees scanned on two separate days. T1ρ imaging was performed using a custom T1ρ pulse sequence (IRB-approved) consisting of a B<sub>1</sub> and B0 compensated T1ρ preparation pulse cluster followed by a chemical shift selective fat saturation pulse and a segmented radiofrequency spoiled 3D gradient echo (SPGR or FLASH, commonly used sequences<sup>4</sup>) readout acquisition with centric phase encoding order. Imaging started with a tri-plane GRE localizer scan. After global shimming, reference frequency and voltage was set corresponding to a small shim volume covering cartilage of interest. MPRAGE sequence was used to acquire anatomical images and used for identifying and locating same position and orientation of knee in two MRI repetitions using Imscribe software.

T1ρ imaging was performed with a spin lock pulse amplitude B<sub>1,sl</sub> = 500Hz and spin lock times (TSLs) = 0, 10, 20, 30, 40ms, 3D-flash readout TR/TE = 9.7/4.9ms, flip angle = 10°, FOV=140×140mm<sup>2</sup>, matrix size = 448×448, slice thickness = 3 mm, number of slices = 10, number of averages = 1, number of shots = 2 and a shot TR of 5s. Phase encoding direction was from R->L with resolution of 50%. Scan time for one set of T1ρ data (slices = 10 and TSLs = 5) was 8 minutes.

**Data Analysis:** T1ρ maps were generated by fitting data voxel-wise to the exponentially decaying function (S (TSL)=S<sub>0</sub>\*exp (-TSL/T1ρ)). ROI analysis was performed in different facets of cartilage. Average, standard deviation and coefficient of variation were computed. In addition, intraclass correlation coefficient (ICC) was also computed for testing reproducibility.

**Results and Discussion:** **Fig. 1** presents the coefficient of variation (CV) from all participating subjects for all three cartilage types: patella, femoral and tibial. The low CV values observed in this study are indicative of a high degree of repeatability, with the combined CV % being less than 4% for patella, femoral, and tibial regions of the articular cartilage. Similarly, ICC was 0.95 (p=0.001) for patella, 0.91 (p=0.007) for femur and 0.93 (p=0.002) for tibia cartilage. ICC of T1ρ values was statistically significant for all the cartilage facets, which confirms the high reproducibility of T1ρ values in all three facets. **Fig. 2** shows the bar plots of average T1ρ values from all the subjects for all three cartilage types. The general T1ρ range of knee cartilage in a healthy individual varies between 40 and 55ms across the cartilage in different compartments. **Fig. 3** comparison of T<sub>1ρ</sub> weighted images and T1ρ maps of knee cartilage, axial and a coronal view, of a healthy volunteer is shown. Arrow (Fig. 3F) indicates the medial side femoral cartilage with reduced contrast among different layers due to magic angle effect. **Fig. 4** displays the comparison between T1ρ maps of the left and right knees of one of the volunteers with occasional knee pain (age = 64). Notable differences are indicated by arrows (Fig. 4B). The right knee (symptomatic) had T1ρ values that were approximately 15% to 18% higher than the left knee cartilage as well as normal tissues of same cartilage. In conclusion, with the described protocol and data presented, T1ρ mapping can be reliably performed at 7T. This has potential clinical applications, as it can provide clinicians the ability to non-invasively identify changes in macromolecular content that are often associated with cartilage related pathologies, including osteoarthritis<sup>3</sup>.

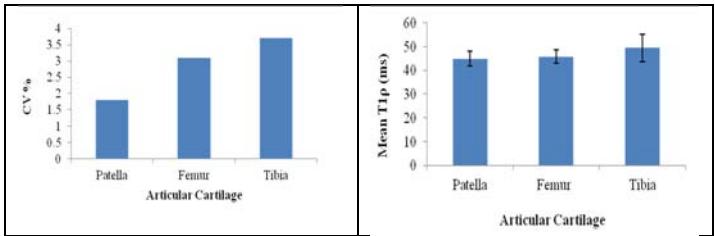


Figure 1: Bar plots of the average CV (%) for all subjects.

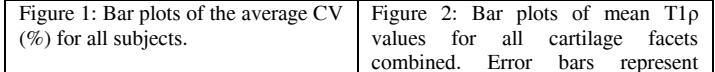


Figure 2: Bar plots of mean T1ρ values (ms) for all cartilage facets combined. Error bars represent standard deviation.

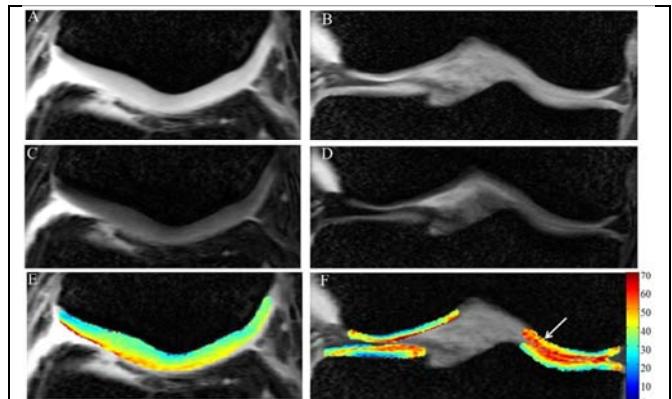


Figure 3: First column images show patellar cartilage in axial orientation and 2<sup>nd</sup> column images show femoral and tibial cartilage in coronal orientation of a healthy volunteer at 7T. First row (A&B) contain high resolution anatomical images (TSL=0), 2nd row (C&D) contain high resolution T1ρ-weighted images corresponding to TSL =40ms and 3rd row contain high resolution T1ρ (ms) maps of cartilage overlaid on anatomical images. Note that these are cropped images.

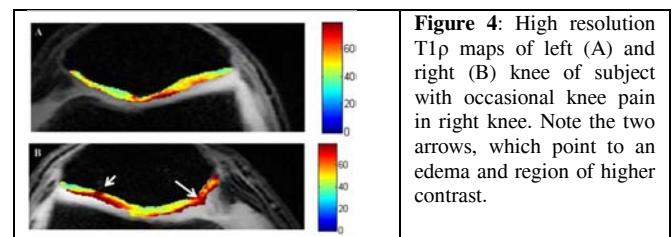


Figure 4: High resolution T1ρ maps of left (A) and right (B) knee of subject with occasional knee pain in right knee. Note the two arrows, which point to an edema and region of higher contrast.

**References:** [1]. Dardzinski, B.J, et al, Radiology-1997, 205(2): 546-55. [2]. Duvvuri, U, et al, Radiology-2001; 220 (3): 822-6. [3]. Borthakur, A, et al., NMR Biomed, 2006. [4]. Fujinaga, Y., et al, JMRI (2013) 220-224. [5]. X. Li, C. Benjamin Ma, et al, Osteoarthritis Cartilage. 2007 July; 15(7): 789-797.