In Vivo High-Resolution Angular/Depth Dependent T2 and $T1_\rho$ Mapping Analysis of Femoral Cartilage at 3T

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Target audience:

Clinicians/researchers in study of cartilage via MR-based mapping techniques for functional assessment.

Purpose:

Compositional MR imaging techniques such as T2 and $T1_\rho$ mapping are promising tools in physiologic quantitative assessment of early osteoarthritic cartilage damage. T2-mapping has been previously demonstrated to be valuable in assessment of hydration content (collagen concentration) and is currently available as a clinical MR-protocol. Although not yet clinically available, $T1_\rho$-mapping has shown to be sensitive to proteoglycan content and promises to be more sensitive for detection of early degeneration of cartilage. It was shown, however, that in order to accurately detect early cartilage damage via T2 map, it is important to identify other factors affecting the T2 value of normal cartilage, such as magic angle effect and laminar anisotropy. Whether or not such factors also affect the $T1_\rho$ value of normal cartilage has not been previously investigated. Based on a novel segmentation approach previously demonstrated to evaluate the magic angle effect in T2 value of cartilage,[1] both T2 and $T1_\rho$ maps of the medial femoral cartilage at 3T were calculated with angular/depth dependent approach and analyzed for their difference.

Methods:

Four knees (mean 44.5 years of age) were used in this study. T2 and $T1_\rho$ images were acquired at a 3T scanner (Philips Medical Systems, Best, Netherlands) utilizing an 8-channel knee coil. Both scans were acquired in 31 sagittal slices sharing the same FOV/slice-thickness (140/3 mm). A multi-echo based TSE sequence (TR=2700 ms w/ 7 TEs ranging from 13 to 91 ms in step of 13 ms) was utilized for T2 mapping. $T1_\rho$ scans with varying spin-lock durations (TSL) were performed using 3D balanced-FFE sequence for $T1_\rho$ mapping (TR/TE=5.9/2.9 ms). Using a rotary echo based $T1_\rho$ preparatory pulses,[2] 4 different TSL values (10,20,40,60 ms) were employed. Images were processed off-line using a custom processing tool prepared in Matlab (the Math Works, Inc., Natick, MA, USA). The realignment tool of SPM software package[3] was utilized in realignment of the images based on rigid-body transformation first between the first series of T2 and $T1_\rho$ sets (TE=13 and TSL=10, respectively) and then the rest of the respective series to its first series prior to a monoexponential fitting for both T2 and $T1_\rho$ on a pixel-by-pixel basis. In order to assess the angular/depth dependency of T2 and $T1_\rho$ values simultaneously, a region-of-interest (ROI) was manually drawn in 1-3 contiguous slices along the normal appearing medial femoral condyle cartilage on the realigned mean T2 and $T1_\rho$ images. Then, the cartilage was angularly segmented as well as into the deep and superficial layers using a custom Matlab script as previously described (Fig.1).[1] ROI-averaged T2 and $T1_\rho$ values from the segmented cartilage were then generated for full thickness, deep and superficial layers of cartilage.
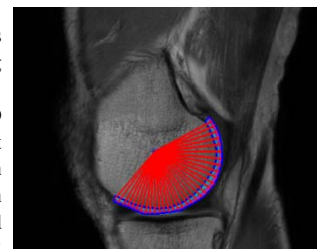

Fig.1: Cartilage ROI further segmented angularly as well as into deep and superficial layers as shown on the realigned mean image.

Results:

Fig. 2 shows a representative proton-density weighted image of the femoral cartilage (left) and color-coded T2 (middle) and $T1_\rho$ map (right) of the full-thickness layer of medial condyle. Fig. 3 shows the angular segmentation-averaged T2 and $T1_\rho$ profiles from 4 knees as a function of their orientation to the static magnetic field, B0, which is along the vertical direction at 0˚. The respective profiles from deep and superficial layers of cartilage were also shown with the standard error as the error bars. The negative/positive angles are defined as anterior/posterior to the center point shown in Fig. 1. Cartilage-depth dependent, magic-angle effect was observed with the T2 profile as previously demonstrated[1] whereas no such effect was observed with the $T1_\rho$ profile.

Fig. 2: A representative T2w image (w/ TE=13 ms) and the segmented cartilage ROI overlaid with color-coded T2 and $T1_\rho$ map from left to right, respectively.
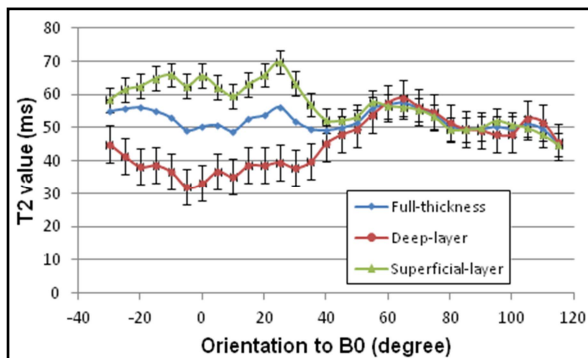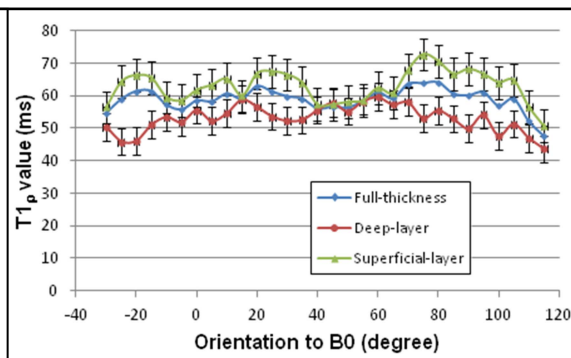

Fig.3: Profile of T2 (left) and $T1_\rho$ (right) as a function of the angular segmentation orientation to the static magnetic field (B0). Three profiles are shown for T2 & $T1_\rho$: full-thickness, deep-, and superficial-layer of cartilage.

Discussion:

The results demonstrate that cartilage-depth dependent, magic-angle effect was observed with T2 but not with $T1_\rho$. Occurrence of the magic angle effect in deep layer of cartilage where maximum T2 relaxation time occurs along 55˚ relative to B0 is thought to be due to anisotropically oriented collagen fibers in the radial zone. In comparison, $T1_\rho$ is thought to be affected by depletion of proteoglycan in pathology of cartilage and our result suggested no directional or cartilage-depth dependency in its value. Although there was a slight tendency for higher $T1_\rho$ value in superficial layer in comparison to that of deep layer with a convergence of their values around 55˚ relative to B0, small sample size and relatively much higher degree of variations prevented us from drawing any definitive conclusion in this study.

Conclusion:

This study demonstrates a high-resolution angular/depth dependent T2 and $T1_\rho$ mapping of femoral cartilage at 3T and subsequent analyses of the resulting maps via a novel segmentation methodology for the potential of quantitative functional assessment of cartilage in vivo.

References:

[1] Somers S, Pham P, Ghosh N, et al. A novel T2 mapping approach that can evaluate magic angle effect and T2 relaxation time in normal knee cartilage of patients from the osteoarthritis initiative. ISMRM 20th Annual Meeting & Exhibition, Melbourne, Australia, 2012. p.1387. [2] Charagundla S, Borthakur A, Leigh J, et al. Artifacts in $T1_\rho$-weighted imaging: correction with a self-compensating spin-locking pulse. J Magn Reson 2003;162(1):113-121. [3] http://www.fil.ion.ucl.ac.uk/spm/software/.