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

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Introduction/Objective: In early knee osteoarthritis, T2 relaxation time increases in cartilage before morphologic changes are visible [1]. Understanding the normal range of T2 relaxation time is essential for detection of early osteoarthritic cartilage damage. However, studies have shown orientation dependent artifactual elevation of T2 relaxation time on curved surfaces such as the medial femoral condyle, possibly related to magic angle effect [2-4]. The purpose of this study is to measure T2 relaxation time in normal appearing knee cartilage using a novel T2 mapping approach that can demonstrate orientation and thickness dependent variations in T2 relaxation time in patients from the Osteoarthritis Initiative (OAI).

Materials and Methods: Data for these analyses are from the T2 map (T2M) sequence (TR 2700, TE 10 to 70, 7 echoes) of the OAI public use data set. Three sagittal first echo T2M images from the center of the medial femoral condyle were selected in all 483 knees of the 0.E.1 incidence cohort for a total of 1449 images. Each image was evaluated by a musculoskeletal radiologist. One image from each knee with normal-appearing medial femoral cartilage free of abnormalities such as signal heterogeneity, focal or diffuse cartilage defects was included in this study (Figure 1). A custom software package using MATLAB (The Mathworks Inc., Natick, Massachusetts, USA) was created to perform the
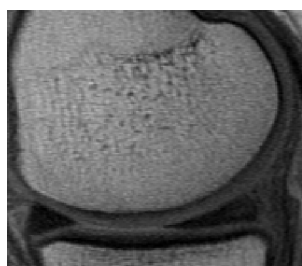

Figure 1: Sagittal first-echo T2 mapping sequence image; TR 2700, TE 10. Normal-appearing medial femoral cartilage.
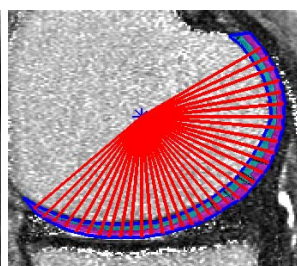

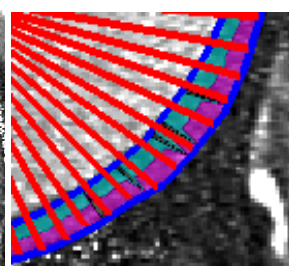Figure 2: T2 Map. Radial lines from a central point divide cartilage into 5 degree segments.

Figure 3: T2 Map. Segmentation of cartilage into deep (0-50%) and superficial layers (51%-100%) of relative thickness.

following T2-mapping approach. A region of interest (ROI) was manually drawn around the medial femoral condyle cartilage on the T2M image. T2M images were converted to T2 maps using a monoexponential curve fit of data from 7 echoes using the equation: $SI(t) = SI0 \cdot \exp(-t / T2)$. SI equals signal intensity and t equals TE. The cartilage ROI was then applied to the T2 map. Radial collagen fibers within cartilage are arranged perpendicular to the subchondral bone [3, 5]. To measure the orientation of these collagen fibers, the medial femoral condyle was assumed to approximate the shape of a circle. A center point that estimates the center of the medial femoral condyle "circle" was manually marked on the T2 map. Multiple lines radiating from the central point separated by 5 degrees were automatically drawn through the cartilage (Figure 2). The main magnetic field (B_0) was defined as 0 degrees. Negative angles are located anterior to the center point while positive angles are located posterior to the central point. This approach was used to define cartilage orientation relative to B_0 in this study. The cartilage was also divided into full-thickness (0-100% relative thickness), deep (0-50% relative thickness) and superficial layers (51%-100% relative thickness) (Figures 2 and 3). The T2 relaxation time of each pixel within a cartilage segment was extracted and averaged, yielding an average T2 relaxation time for each individual cartilage segment. T2 relaxation time was plotted as a function of orientation to B_0 (T2 profile). T2 profiles were generated for full thickness, deep, and superficial layers of cartilage (Figure 4).
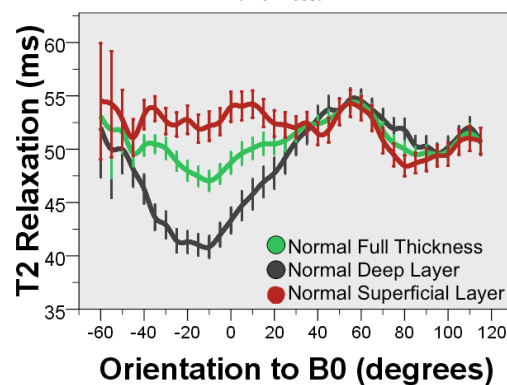

Figure 4: Normal T2 profiles for full thickness, deep, and superficial cartilage layers show magic angle effect is significant in deep layers; intermediate in full thickness; and minimal in superficial layers. Vertical bars are 95% confidence intervals.

Results: Image analyses yielded 105 patients without medial femoral cartilage signal heterogeneity, focal or diffuse defects (mean age 56.9 years, 51% female). The deep layer of cartilage demonstrates the lowest T2 relaxation time at approximately -25 to -15 degrees and a gradual increase in T2 relaxation time with a maximum value at 55 degrees (54.7 ms ± 95% confidence interval 1.02 ms) (Figure 4). The peak T2 relaxation time at 55 degrees is 26% longer than at 0 degrees (54.7 ms/43.4 ms). Full thickness cartilage demonstrates a less rapid increase in T2 relaxation time as angles approach 55 degrees, and the superficial layer shows the least T2 relaxation time variability with increasing angles. Above 55 degrees, cartilage T2 relaxation time of the superficial and deep layers is not significantly different.

Conclusion: An orientation and thickness dependent T2 mapping approach can detect T2 relaxation time variability related to magic angle effect. In the present study, magic angle effect occurred throughout the majority of cartilage, but predominated in the deep layer where collagen fibers are anisotropically oriented in the radial zone. T2 relaxation time is maximum in the deep layer when collagen fibers are oriented 55 degrees relative to the main magnetic field. The results in the present study emphasize the importance of evaluating deep and superficial cartilage separately, as well as considering orientation to the main magnetic field when T2 mapping is used for diagnosis of cartilage lesions.

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