Orientation and thickness dependent T2 mapping analysis of early knee cartilage degeneration using data from the Osteoarthritis Initiative.

Peter Huy Pham[1], Scott Somers[2], Nirmalya Ghosh[3], and Hiroshi Yoshioka[1]

[1]*Radiologic Sciences, University of California, Irvine, Orange, CA, United States,* [2]*Radiology, Loma Linda University Medical Center, Loma Linda, CA, United States,* [3]*Non-invasive Imaging Lab, Loma Linda Univeristy Medical Center, Loma Linda, CA, United States*

Introduction and Objectives: In the pathogenesis of osteoarthritis, degraded hyaline articular cartilage develops elevated water content before cartilage loss or clinical symptoms (1,2). T2 mapping allows non-invasive evaluation of articular cartilage hydration (3) and may be a biomarker for early cartilage damage. However, articular cartilage T2 mapping is susceptible to magic angle effect because of the collagen fiber orientation and laminar organization in cartilage (4). The purpose of this study is to detect early knee cartilage damage and distinguish it from magic angle effect and laminar anisotropy using a novel orientation and thickness dependent T2 mapping approach in the incidence cohort of the Osteoarthritis Initiative (OAI).

Materials and Methods: Data for these analyses are from the T2map (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 from all 483 patients of the 0.E.1 incidence cohort. A total of 1449 images were evaluated. One image from each knee demonstrating lesions of a) signal heterogeneity or b) focal defect less than 1 cm on visual analysis was included in this study. Each lesion seen on the T2M images was given an orientation to the main magnetic field (B0) in degrees (Figure 2A). Custom software was used in the following steps: manually draw a region of interest around the medial femoral condyle cartilage; convert T2M images to T2 maps using a monoexponential curve fit of data from all 7 echoes; divide cartilage into segments that are 5 degrees thick (orientated to B0) by 50% relative depth (deep and superficial); and extract T2 relaxation times from each cartilage segment. T2 relaxation times were plotted as a function of orientation to B0 (T2 profiles) for lesions a) and b) above. These lesion T2 profiles were overlaid on normal control knee cartilage T2 profiles defined in a companion study of 105 normal-appearing knees from the same OAI cohort (Figure 1). Two different radiologists independently performed T2M image analysis and T2 profile evaluation. T2 profiles were compared with corresponding T2M images for lesion matches. A lesion match is defined as a clear deviation of T2 relaxation time from normal control T2 relaxation time in a similar orientation to B0 as a lesion seen on T2M images.

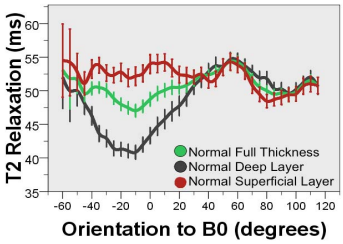

Figure 1: Normal T2 profiles for full thickness, deep, and superficial cartilage layers show magic angle related T2 elevation is maximal in the deep layer; intermediate in full thickness; and minimal in the superficial layer. Vertical bars are 95% confidence intervals.

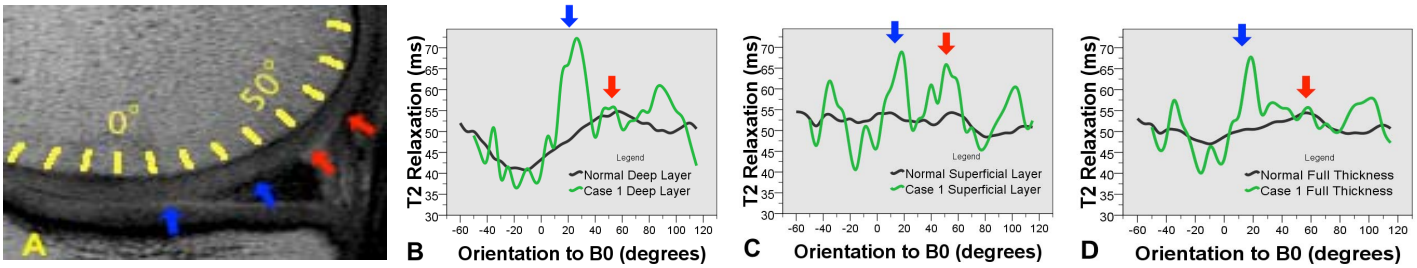

Figure 3: A) T2map sequence image (TR 2700, TE 10) shows full thickness signal heterogeneity between the blue arrows and superficial signal heterogeneity between the red arrows. B0 is parallel to 0 degrees. Each hash mark equals 10 degrees. B,C,D) Deep, superficial, and full thickness layer T2 profiles show elevated T2 relaxation times (blue and red arrows) relative to normal controls in the same orientation to B0 as in Figure A, representing two lesion matches.

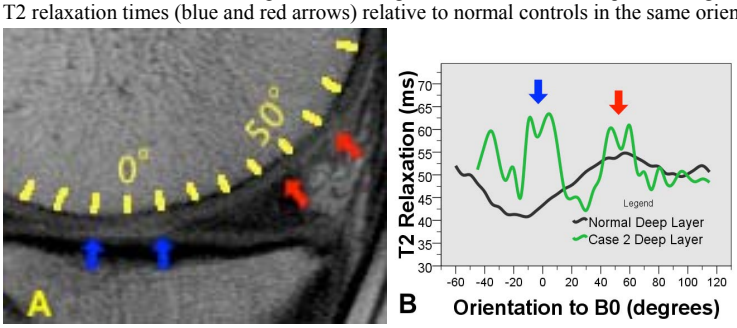

Figure 2: A) T2map sequence image (TR 2700, TE 10) shows focal cartilage defects less than 1 cm between blue arrows and red arrows. B0 is parallel to 0 degrees. Each hash mark equals 10 degrees. B, C) Deep and superficial layer T2 profiles show elevated T2 relaxation times (blue and red arrows) relative to normal controls in the same orientation to B0 as in Figure A, representing two lesion matches.

Results: Out of 1449 images, 26 images (mean age 59 years, 54% female) with signal heterogeneity and 27 images (mean age 60 years, 33% female) with focal defects less than 1 cm were selected for T2 mapping analysis. In knees with visually detected signal heterogeneity lesions, 85% (22/26) of T2 profiles demonstrated a lesion match with T2M images. T2 profiles of signal heterogeneity lesions demonstrated clear deviation from normal T2 profiles with higher peak in superficial and/or deep layers in similar orientation to B0 as T2M images (Figures 2A,B,C, blue arrows). Additionally, in this case, subtle signal abnormality located in the superficial layer at 45-60 degrees (Figure 2A, red arrows) could represent magic angle effect. However, superficial T2 profile (Figure 2C, red arrow) shows that T2 values at 45-60 degrees are significantly higher than expected for magic angle effect as seen in the normal superficial T2 profile (Figure 2C, black curve). Deep and full-thickness analysis does not demonstrate this lesion well (Figures 2B,D, red arrows). This result indicates the importance of separate superficial and deep layer analysis, rather than full thickness analysis alone. All (27/27) knees with focal defects less than 1 cm demonstrated lesion matches between T2 profiles and T2M images (Figure 3).

Discussion: Orientation and thickness dependent T2 mapping is a sensitive method to detect early knee cartilage degeneration such as signal heterogeneity or focal defect less than 1 cm in patients from the OAI. This approach can also distinguish true cartilage lesions from magic angle effect and allows separate analysis of deep and superficial layers of cartilage to increase sensitivity for detection of early knee cartilage degeneration.

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