UTE imaging of the patella with bi-component analysis: correlation with histopathology and polarized light microscopy

Jiang Du[1], Chantal Pauli[2], Won Bae[1], Martin Lotz[2], Graeme M Bydder[1], Darryl DLima[2], and Christine B Chung[1]

[1]*Radiology, University of California, San Diego, San Diego, California, United States,* [2]*Scripps Clinic, San Diego, California, United States*

INTRODUCTION

The majority of the water in cartilage exists in the form of free water, with a smaller fraction bound to either PG or collagen fibrils [1, 2]. Bound water has a much shorter T2 than free water. Ultrashort echo time (UTE) sequences have been developed to image short T2 tissues or tissue components in vitro and in vivo and have been implemented on clinical MR scanners [3]. In this study we aimed to evaluate cadaveric human patellae using UTE imaging with bi-component analysis to quantify the short and long T_2^* water components and correlate the results with conventional histology and polarized light microscopy (PLM). Clinical T2 measurements were also performed for comparison.

MATERIALS AND METHODS

Twenty fresh human patellae from 11 donors (7 males, 4 females; age range = 48-92, mean 67.2 ±17.9 years) were obtained from tissue banks and processed within 24-72 hours of death. After harvesting, a transverse slab of 5-8 mm thickness was prepared for MR imaging. A single slice at the center of each patella sample was imaged with the apex normal to the B_0 field. A 2D UTE imaging sequence was used for data acquisition with the following parameters: TR = 200 ms, FOV = 6 cm, matrix = 512×512, slice thickness = 1.7 mm, 13 TEs ranging from 8 µs to 80 ms, 2 minutes per image. CPMG acquisitions with 8 echoes were acquired with the same spatial resolution and a 12 minute scan time. After MRI the patellae slabs were prepared for histology. 5 µm sections were cut at the defined location to match the MRI scans. Several sections from each patella were stained with Safranin O-Fast Green for histopathology and Picrosirius Red for polarized light microscopy (PLM).

Four to six regions of interest (ROI) were chosen per patella for correlation of histopathology, PLM and MRI. The number of regions was determined by one author depending on the grade of OA severity. Each ROI was given a Mankin score [4] ranging from 0 to 14. Each score was converted to a grade as follows: G1 = 0-1, G2 = 2-5, G3 = 6-9, G4 = 10-14. Each ROI was also qualitatively assessed using the grading scale (grade 0-4) published by Vaudey to describe the birefringence characteristics of the articular cartilage matrix [5].

Single-component fitting was performed on data from the CPMG images for T2 measurement. Bi-component fitting was performed on data from the UTE images for bound and free water T2* and fraction measurements [3]. Short and long T2* values and their fractions, as well as T2, were correlated with the Mankin and Vaudey scores.

RESULTS and DISCUSSION

OA is a complex disease which displays considerable heterogeneity. Figure 1 shows an example with histology, PLM and UTE images as well as bi-component analysis of three ROIs with mild, moderate and severe degeneration, respectively. UTE bi-component analysis shows a significant increase in short T2* water fraction from 21.9% for mild OA, to 28.5% for moderate OA and 36.0% for severe OA.

Figure 2 shows the T2 analysis of a healthy patella. At later echoes signal from ROI #2 (near the magic angle) is significantly higher than that from ROI #1. T2 was 79.27 ms for ROI #2 and 30.68 ms for ROI #1, corresponding to an increase of 158%. The UTE images also showed significant apparent magic angle effects on their T2* values. However, short T2* water fraction, 20.7% for ROI #1 and 18.8% for ROI #2, appeared less sensitive to the magic angle effect.

Figure 3 shows the correlation between CPMG T2, UTE bound water fraction and the Mankin and Vaudey scores in 91 regional ROIs. There is a low correlation between T2 and Mankin/Vaudey scores probably due to confounding factors introduced by the magic angle effect which may result in a several fold increase in T2 [6]. This increase may exceed the change produced by OA. However there is a much stronger correlation between bound water fraction and Mankin/Vaudey scores. Articular cartilage contains numerous collagen fibrils which bind proteoglycan into a structural gel that traps water [7, 8]. Disorganization of the collage matrix may result in a significant increase in surface area available for water binding and thus a significant increase in total bound water fraction [8].

CONCLUSIONS

In conclusion, we have shown that UTE bi-component analysis can be performed with a clinical imager to evaluate short T2* (bound water) and long T2* (free water) components in articular cartilage. Short T2* water fraction probably reflects collagen matrix degradation and is significantly correlated with cartilage degeneration. CPMG T2 values are poorly correlated with histology and PLM.

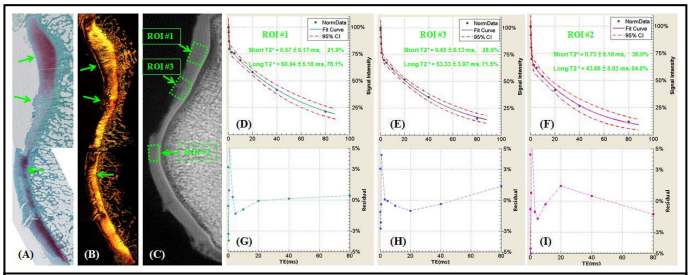

Fig 1 *Histology (A), PLM (B) and UTE imaging (C) of a patella specimen, and bi-component analysis of ROI #1 with mild OA (Mankin score 2, Vaudey score 0) (D, G), ROI #2 with moderate OA (Mankin score 7, Vaudey score 2) (E, H), and ROI #3 with severe OA (Mankin score 12, Vaudey score 3) (F, I). Bi-component analysis shows that short T2* fraction increased from 21.9% for mild OA, to 28.5% for moderate OA and 36.0% for severe OA. The residual signal (G-I) is less than 5%, suggesting that the bi-component model is well suited for UTE T_2^* analysis of cartilage.*

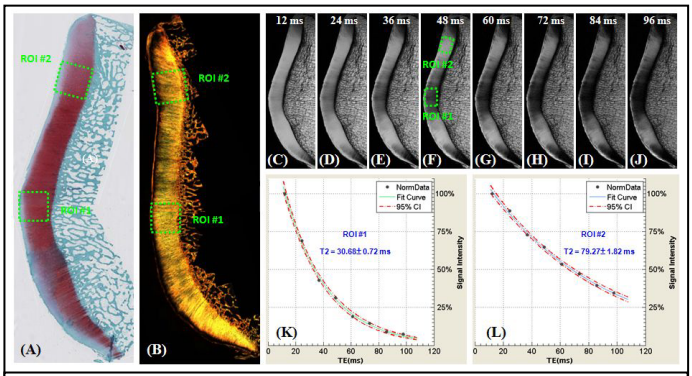

Fig 2 *Magic angle effect inT2 analysis of a patella sample with normal histology (A) and PLM (B) as well as CPMG images with TEs of 12-96 ms (C-J), and single component T2 fitting of two ROIs: ROI #1 (K) and ROI #2 (L). The ROIs show a dramatic T2 increase from 30.68 ms for ROI #1 (K) to 79.27 ms for ROI #2 (L) although both ROIs have the same normal Mankin scores of 1 and Vaudey scores of 0.*

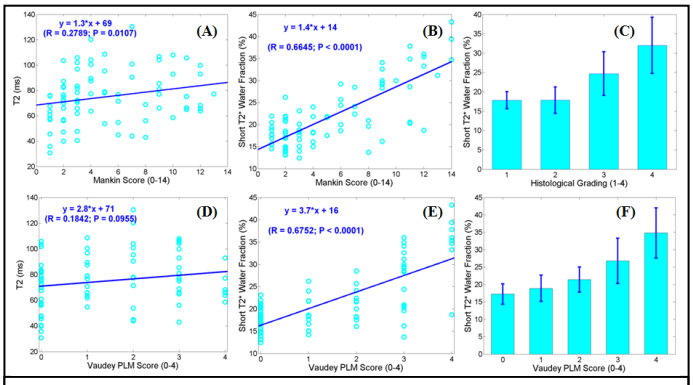

Fig 3 *Correlation between CPMG T2 and bound water fractions with the Mankin score (A, B) and Vaudey score (D, E), as well as the relationship between bound water fractions and histological grading (C) and Vaude PLM score (F). Bound water fraction is positively correlated with the Mankin (Rho = 0.6681, P < 0.0001) and Vaudey (Rho = 0.6461; P < 0.0001) scores, while CPMG T2 is only weakly correlated with the Mankin (Rho = 0.2789; P = 0.0107) and Vaudey (Rho = 0.1842; P = 0.0955) scores. There is a steady increase in bound water fraction with histological grading and Vaudey score.*

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