3D Visualization of Quantitative T_2 Relaxation Times in the Femoral Condylar Cartilage in Healthy and ACL-injured Individuals

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PURPOSE: Osteoarthritis (OA) is a degenerative joint disease that may affect more than half of the ACL-injured population[1]. Parametric MRI mapping (such as T_2) can help assess cartilage molecular composition and may provide an objective outcome measure for the early degenerative changes of OA[2,3]. Despite the acquisition of 3D, quantitative data, current MRI studies often evaluate just a single slice from the medial and lateral compartments of the full knee[2,3,4]. Single-slice assessment may not fully describe the cartilage variation and may obscure longitudinal changes. Studies that have performed the flattening of cartilage for full volume analysis have either focused on thickness[5] or texture analysis[6,7]. Here we provide a method of visualizing quantitative cartilage data that fully utilizes the 3D volumetric acquisition by projecting the femoral articular cartilage onto a 2D map.

METHODS:

Acquisition: Quantitative double-echo in steady-state (qDESS)[8] imaging was performed at 3T using a transmit-receive 8-channel knee coil, 3mm slice thickness, 16cm FOV and a 256x256 matrix. With IRB approval, five healthy volunteers were scanned at baseline, 24 hours later at day 2, and 1 year later. Five ACL-injured patients were scanned at baseline (approximately 1 month after surgical reconstruction), 6 months and 1 year later.

Visualization: Slice-by-slice manual cartilage segmentation was performed on the qDESS images using software developed in Matlab. qDESS images were used to generate T_2 maps using OsiriX, and the segmented boundaries were superimposed on these maps (Fig. 1A). The segmented femoral cartilage of the knee was fit to a cylindrical surface (Fig. 1B). Radial projections from the cylinder center at fixed increments of 1^o (from 0^o to 245^o) were superimposed on each slice and the quantitative T_2 values that fell between consecutive projections were averaged to form a 2D map (Fig. 1C).

Reproducibility: Reproducibility measurements were performed on five healthy volunteers at day 1 and day 2. The short-term percent coefficient of variation (CV%) for T_2 relaxation times within the manually registered visualization maps was calculated for each angular bin. Global CVs were calculated by averaging across all slices.

Longitudinal Analysis: Within both populations, visualization maps were created for each time point. Difference maps between the baseline and the one-year scans were calculated (Fig. 2). A difference threshold, described as the average mean absolute difference of the healthy population, was used to isolate differences between the healthy and ACL-injured groups. The percentage of the difference maps above this threshold was calculated.

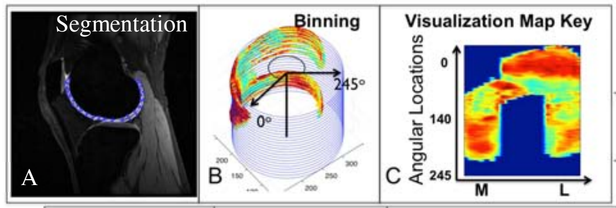

Fig 1: (A) Cartilage Segmentation (B) Cylindrical surface fitting and radial projection at fixed 1° increments (C) Visualization Map of the femoral condyle showing T2 quantitative data per angle and slice locations.

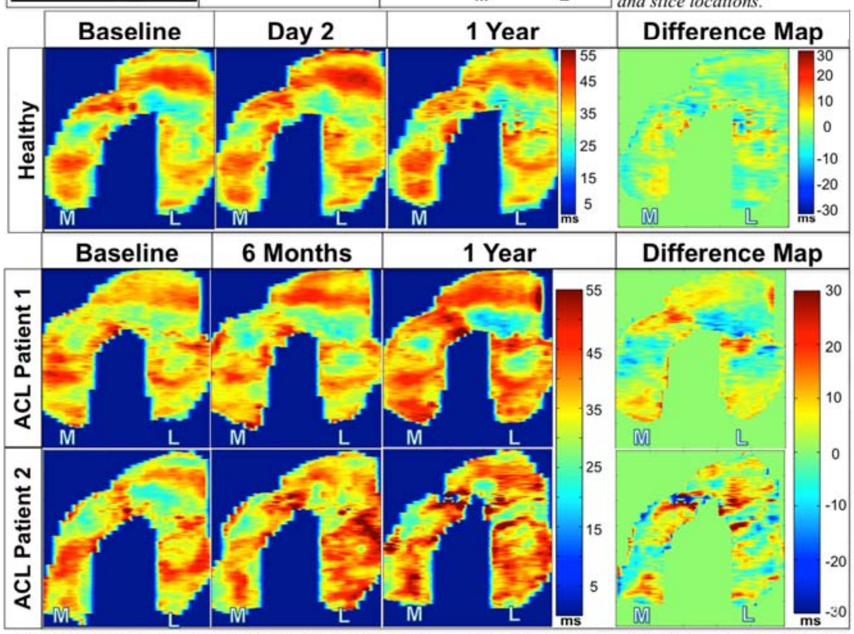

Fig 2: Visualization maps for 3 time points in 1 healthy volunteer and 2 ACL-injured patients. Difference map calculated between the manually registered year 1 and baseline maps. Boundary values eroded to account for poor registration.

RESULTS: The root-mean-square (RMS) bin-wise short-term CV (CV_{RMS}) for all five controls was 19.8% at each pixel while the global short-term CV_{RMS} was 7.9%. The calculated difference threshold was 5ms. Within the ACL-injured population, an average of 47% of the difference map pixels showed T_2 changes above the threshold while the healthy volunteers had an average of 33% above this threshold.

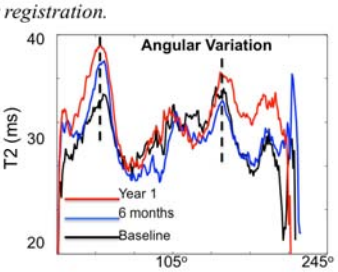

Fig 3: *T_2 angular variation from baseline, 6 months and 1 year of ACL patient 1. Dashed lines indicate T2 elevation due to magic angle effects.*

DISCUSSION: Evaluating cartilage in a limited number of slices may not accurately represent the true distribution of quantitative data. With the proposed volumetric analysis, we can better understand the physiological distribution of cartilage markers within different populations and potentially become better at understanding the OA process. Initial analysis has shown that the angular-bin-wise CVs are elevated, which is expected due to increased coverage of segmentation and the displayed variation (Fig. 3) across the femoral cartilage. The global CV, which is more similar to the ROI approach commonly used, has comparable values to those reported in literature[9]. This tool may be useful for evaluating OA progression, quantifying of local defects and carrying out longitudinal comparisons across healthy volunteers and patients.

CONCLUSION: We have demonstrated a method of fully utilizing 3D acquisitions to visualize quantitative cartilage data. Differences in the visualization maps between healthy volunteers and ACL-injured subjects for T_2 relaxation times are clear. This technique is not constrained to T_2 and can be used to visualize other quantitative parameters such as $T1_\rho$ and sodium.

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