Investigation of In-vivo Relationship between Cartilage Contact and Cartilage Quantitative MR Parameters

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Introduction: Osteoarthritis is common in patients following anterior cruciate ligament (ACL) reconstruction surgery (1). Alterations in cartilage loading after ACL reconstruction surgery have been documented (2) and may play a role in the pathogenesis of post-traumatic osteoarthritis (3). In this study, we implemented a novel technique combining dynamic and static quantitative magnetic resonance (MR) imaging for investigating the in-vivo relationship between cartilage contact, cartilage morphology, and MR biomarkers of cartilage composition and ultra-structure. Successful implementation of this MR technique will establish an efficient infra-structure for use in future longitudinal studies to investigate the hypothesis that changes in cartilage loading contribute to the pathogenesis of post-traumatic osteoarthritis following ACL reconstruction surgery.

Methods: The study was performed on the left knee of a 23 year old male subject 20 months following successful ACL reconstruction surgery who had no evidence of cartilage or meniscal injury at arthroscopy. The subject underwent a dynamic and static quantitative MR protocol on a 3.0T scanner (Discovery MR750, GE Healthcare). For the dynamical protocol, the subject was placed supine into an MR-compatible loading device. The subject actively flexed and extended his knee at 0.5 Hz for 5 minutes while dynamic SPGR-VIPR (1.5x1.5x1.5 mm, FOV= 48 cm, 60 frames) images were continuously collected (4). The static protocol included a 3D fast spin-echo (3D-FSE) sequence (0.4x0.4x1.0mm resolution) and an mcDESPOT bi-component T2 mapping sequence (0.6x0.6x3.0mm resolution) performed using a series of SPGR scans, bSSFP scans, and an IR-SPGR scan (5). Femoral and tibia bone and cartilage volumes were manually segmented from the 3D-FSE images. Tibia plateau cartilage volumes were used to compute the cartilage thickness (Th) map. Segmented bone and cartilage models were registered to each dynamic image frame to reconstruct the 3D tibiofemoral kinematics throughout the knee motion cycle. Reconstructed kinematics were used to compute the tibia plateau contact map which was defined as the maximum depth of penetration of the tibia cartilage mesh into the femoral cartilage mesh through the flexion-extension cycle. The single-component T2 relaxation time (T2) map and fast relaxing water fraction map (F_f) were reconstructed using the mcDESPOT method (5). To represent the 3D tibia contact map and quantitative MR maps for convenient visualization, a 2D projection method was performed in the superior-inferior direction where the average value was calculated for cartilage voxels through each projection line. The projected maps were then sub-divided into 10 equal-sized regions of interest (ROI) on the medial and lateral tibia plateau, each of which contains 400 voxels. ROI-based Pearson correlation analysis was performed between the cartilage contact map and the cartilage MR parametric maps.

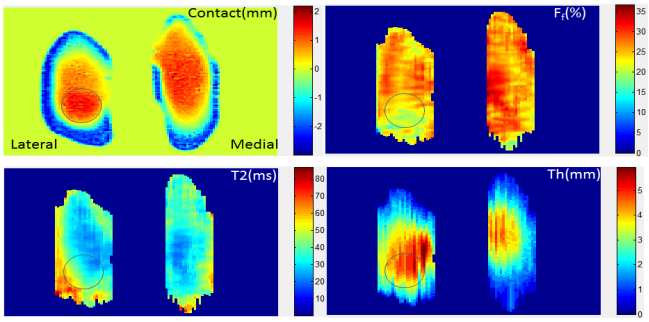

Figure 1: Comparison between tibia plateau cartilage contact map, thickness (Th) map, and mcDESPOT parametric (F_f and T2) maps after 2D projection analysis. Note the circle indicates the posterior contact shift on the lateral tibia plateau which corresponds to an area of decreased F_f and increased T2 on the mcDESPOT parametric maps.

Results: Figure 1 shows the cartilage contact map, thickness map, and mcDESPOT parametric maps of the tibia plateau. Relative to the contralateral knee (not shown), there was an observed posterior contact shift (indicated by the circle) on the lateral tibia plateau for the subject following ACL reconstruction surgery. There was a significant negative correlation between cartilage T2 and cartilage contact and significant positive correlation between cartilage thickness and cartilage contact for both the medial and lateral tibia plateau with stronger correlation (smaller *p*-values) for the medial tibia plateau. There was also a significant positive correlation between cartilage F_f and cartilage contact for the medial tibia plateau (Table 1).

Pearson Correlation		T2	F_f	Th
R	Lateral	-0.6682	0.4920	0.8628
	Medial	-0.7646	0.7553	0.8658
p-value	Lateral	0.0175	0.1043	0.0003
	Medial	0.0023	0.0028	0.0001

Table 1: Pearson correlation analysis.

Discussion: In this study, we introduced a novel MR technique for investigating the *in-vivo* relationship between cartilage contact, cartilage morphology, and MR biomarkers of cartilage composition and ultra-structure. Thicker cartilage and lower cartilage T2 were noted in the central medial and lateral tibia plateau and were correlated with areas of greater cartilage contact. The lower cartilage T2 in areas of greater cartilage contact are likely due to a thicker deep zone of cartilage with bundles of collagen oriented radially from the subchondral bone which, along with the thicker cartilage, allow the tissue to better withstand high compressive forces (6). As the fast relaxing water fraction (F_f) in cartilage measured using bi-component T2 analysis is felt to represent water bound to proteoglycan (7), the correlation between cartilage F_f and cartilage contact may reflect higher concentrations of proteoglycans in areas of higher cartilage loading which has been documented in previous studies (8). The correlation between cartilage contact and cartilage quantitative MR parameters, especially F_f and T2, was higher in the medial tibia plateau than the lateral tibia plateau where there was a notable posterior shift in cartilage loading. The decreased correlation in the lateral tibia plateau may be due to early cartilage degeneration in the area of abnormally high cartilage loading with an associated decreased F_f (e.g. reduced proteoglycan concentration) and increased T2 (e.g. disorganized collagen ultra-structure). However, this explanation is purely speculative. Additional longitudinal studies using this novel MR technique are needed to better understand the changes in cartilage loading which occur following ACL reconstruction surgery and how changes in cartilage loading may influence changes in cartilage quantitative MR parameters and the eventual development of osteoarthritis.

References: (1) Ajuied A, AJSM, 2014, (2) Tashman S, COOR, 2007, (3) Andriachi T, JBJS 2009. (4) Kaiser J, MRM, 2014. (5) Liu F, JMRI, 2014. (6) Goodwin D, AJR, 2000. (7) Reiter D, MRM, 2011. (8) Rogers B, JBJS, 2000.

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