The Effects of Acute Loading on Knee Cartilage Composition: A Quantitative Magnetic Resonance Imaging Analysis

INTRODUCTION

Diagnosis of osteoarthritis (OA) is typically performed through identification of osteophytes and joint space narrowing on radiographs. However, the earliest changes in joint degeneration are alterations in the biochemistry of the extracellular cartilage matrix. Given as such, considerable efforts have recently been focused on investigation of cartilage biochemistry through new advancements in MRI technology.1,2 More specifically, T1rho and T2 relaxation time mapping has been developed as a method to quantify cartilage composition in vivo. It has been demonstrated that T1rho relaxation time mapping is negatively correlated with proteoglycan content while T2 relaxation time is positively correlated with cartilage water content and collagen disorganization.1,2 While breakdown of supportive tissues such as the meniscus is common in OA, the relationship between MRI relaxation time mapping and meniscus changes is less clear.

Loading plays a major role in the development of OA. Two recent studies have evaluated the effects of acute loading on T2 relaxation time of knee cartilage.3,4 While both studies reported decrease in T2 times, indicating a loss of water content, the findings were not uniform throughout the knee cartilage. To date, no studies have evaluated the effects of loading on T1rho times of cartilage. Similarly, the behavior of meniscus T1rho times during loading has not been investigated.

Therefore, the purpose of the current project is to expand on the previous work in this area through a comprehensive evaluation of acute loading on knee articular cartilage and meniscus T1rho and T2 relaxation times. We hypothesize that both T1rho and T2 times will decrease in cartilage and meniscus during loading.

METHODS

Twenty females with radiographic evidence of OA and ten healthy age-matched female controls participated. First, subjects were positioned in supine on top of a custom-designed loading device on the MR table with no load applied. Subjects’ test lower extremity was positioned in 15 degrees of knee flexion and 10 degrees of foot external rotation (placed on the loading device footplate and supported in place.) Images of the subjects’ knee were acquired as described below. During the second phase of the study, a load equal to 50% of the subjects’ body mass was applied to the loading device resulting in loading of the subjects’ lower extremity (Figure 1). An identical set of images were acquired for the loaded condition as describe below.

MR Acquisition & Analysis. Imaging was performed with a 3T GE MR scanner and an 8-channel phased array knee coil. Coronal 3D T1rho-weighted images were acquired with the following imaging parameters: TR/TE = 9.3/3.7 ms; FOV = 6-8 cm, matrix=256 x 128, slice thickness=3 mm, BW=31.25 kHz, VPS=64, Trec=1.5 s, TSL=0, 10, 40, 80 ms, FSL = 500 Hz. T2 mapping was performed immediately after the T1rho sequence by adding a nonselective T2 imaging sequence with TR/TE=2000/4.1,14.5,25,45.9 ms. T1rho and T2 maps were quantified on a pixel-by-pixel basis. In-plane spatial resolution for both map sequences was 0.5 x 0.5 mm.

Cartilage masks were segmented semi-automatically on high-resolution SPGR images that were registered to the T1rho map using an in-house spline-based developed program. Slice selection was determined based on load bearing areas of the cartilage. The same number of slices was segmented in the unloaded and loaded conditions for each subject. Due to the difficulty in determining borders between femoral cartilage on tibial cartilage during loaded imaging, each compartment (medial and lateral) was assessed as a unit (i.e. medial femoral cartilage + medial tibial cartilage = medial compartment, etc.) On a subset of 20 subjects (12 OA, 8 controls) medial and lateral meniscus masks were manually created using T1rho-weighted images with TSL=40ms.

The segmented 3D masks were then applied to the T1rho and T2 maps for quantification. Average T1rho and T2 relaxation times of cartilage were compared between conditions (unloaded vs. loaded), between compartments (medial vs. lateral) and between groups (OA vs. controls) using a 3-way ANOVA with repeated measures. This was repeated for meniscus T1rho data as well.

RESULTS

With regard to T1rho relaxation time of cartilage, a significant main effect was observed for loading condition (p=0.001) and for OA status (p<0.05). In addition, a significant loading condition x compartment interaction was observed (p=0.001). No other interactions or main effects were observed (p>0.05). Post hoc analysis revealed that when collapsed across group status, the medial compartment showed significant decrease in T1rho relaxation time (40.2 ± 4.8 vs. 44.5 ± 3.8 ms for loaded and unloaded, respectively, p<0.001), while the lateral compartment was not significantly different (41.6 ± 5.5 vs. 42.0 ± 4.5 ms for loaded and unloaded, respectively, p>0.05).

For T2 relaxation time, a significant loading x condition effect was noted (p=0.026). No interactions or other main effects were observed (p>0.05). When averaged across groups and compartments, loading resulted in a significant decrease in T2 relaxation time (30.8 ± 3.6 vs. 31.7 ± 3.1 ms for loaded and unloaded, respectively).

Meniscus T1rho showed a significant group effect. When averaged across menisci and loading condition, the OA group showed significantly higher values for T1rho (17.6 ± 2.7 vs. 15.1 ± 3.3 ms for loaded and unloaded, respectively, p=0.019). No other main effects or interactions were observed.

DISCUSSION

The significant condition effects observed for both T1rho and T2 of cartilage suggest that acute loading results in a decrease in water content and an increase in proteoglycan concentration. Interestingly, the effect appears to be most evident in the medial compartment (Table). Clinically, OA is more frequently observed in the medial compartment. These findings may support the hypothesis that medial compartment loading occurs to a greater extent than the lateral compartment during acute loading. The lack of interaction between OA status and loading condition indicates that the effect of loading on T1rho and T2 times occurs regardless of OA status. Our finding of significant decreases in T2 is consistent with the literature that has reported similar findings in various cartilage locations.3,4

Contrary to our hypothesis, meniscus T1rho failed to show a significant change during loading conditions. However, our data support previous studies that have reported elevated meniscus T1rho in OA subjects compared to controls.3

In conclusion, these data indicate that with acute loading, cartilage water content decreases and proteoglycan concentration increases. A better understanding of how loading influences cartilage biochemistry may provide valuable in the treatment and/or prevention of OA.


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