

Significant Influences of Loading on T1 in Sub-tissue Zones of Canine Articular Cartilage in Experimental OA

Jihyun Lee¹ and Yang Xia¹

¹Physics and Center for Biomedical Research, Oakland University, Rochester, Michigan, United States

TARGET AUDIENCE

Clinical radiologists and basic science researchers who use MRI to study the degradation of articular cartilage associated with various forms of arthritis.

PURPOSE

It is difficult to define the initial stages of osteoarthritis (OA) clinically with the current imaging techniques because many changes in the fine structure and delicate chemical/molecular composition in cartilage proceed significantly prior to the development of OA as a clinical disease. One imaging protocol in MRI is the delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), which is able to evaluate glycosaminoglycan (GAG) content in cartilage quantitatively via the measurements of T1 relaxation time in the presence of the contrast agent Gd-DTPA²⁻. The aim of this study was to determine the effects of external loading on T1-Gd relaxation times in healthy and ACL-induced osteoarthritic articular knee cartilage at high resolution.

METHODS

Six mature dogs underwent anterior cruciate ligament transection (ACLx) in one knee were studied. Animals were sacrificed 8 weeks post surgery, which were handled according to the protocols approved by the Institutional Review Boards. Five rectangular blocks were harvested from each medial tibia from both knees (ACLx and contralateral). Each block was immersed in 1mM gadolinium contrast agent and stored at 4°C until imaging at the magic angle. Quantitative μ MRI T1-Gd imaging experiments were performed on a Bruker AVANCE II 300 NMR spectrometer equipped with a 7-Tesla/89-mm vertical-bore superconducting magnet and micro-imaging accessory. The echo time (TE) was 7.2 ms and the repetition time (TR) was 0.5 s. The imaging slice thickness was 0.8 mm, which was transversely located in the middle of the 4–6 mm-long specimen. The 2D in-plane pixel size was 17.6 μ m. The measurement of 2D T1 images used the inversion recovery sequence with five inversion points (0, 0.1, 0.3, 0.5, 1.0 s). The T1-Gd images were obtained twice for each specimen: when the tissue was unloaded and loaded (up to ~60% strain) by a loading device. (Note: The data of normal cartilage (N=7) from a related project was used for statistical comparison.)

RESULTS

Fig 1 showed a representative set of T1-Gd images of the medial tibia joints of (a) unloaded and (b) loaded (strain %) of three disease stages: ACLx (25%), Contralateral (30%), and Normal (30%). The images (Fig 1-a) and profile (Fig 2, solid \blacklozenge \bullet $\color{red}\bullet$) of T1 in the unloaded cartilage showed an increasing trend from the surface to deep cartilage in all specimens. At all sub-tissue zones, the mean T1-Gd values from the meniscus covered area were higher than those from the uncovered area for all X, C, N with highly significance (not shown). Between X and C, the T1-Gd of X was significantly lower than C in RZ1, RZ2, and bulk ($p<0.001$); lower but not significant in SZ ($p=0.712$) and TZ ($p=0.053$). Loading increased the mean T1-Gd values significantly near the surface (SZ, TZ) and RZ1, but not significantly in deep cartilage near the bone (RZ2) for all X, C, and N (Fig 2, open symbols). Fig 3 compared the bulk values among X, C, and N specimens, by (a) one-way ANOVA in the unloaded samples (0.01089), and (b) the paired student t-test between unloaded (solid colors) and loaded (shaded boxes) for each stage (***: $p<0.001$). The average strain (%) was 27 ± 14 for X, 22 ± 14 for C, and 24 ± 7 for N. The T1-Gd change with strain showed a trend towards smaller values from the articular surface (SZ) to the TZ, RZ1, and further to RZ2 for both covered and uncovered areas by meniscus at all X, C, and N. Table 1 showed the topographical map of T1-Gd at each sub-tissue zone as well as the total (bulk) values in the unloaded samples.

DISCUSSION:

This study characterized and mapped experimental canine OA knee cartilage with the T1-Gd protocol, reflecting early degradation. We measured mean T1-Gd in each sub-tissue zone. Significant differences were observed in most of sub-tissue zones as well as bulk. We found

topographical variations of T1-Gd between the meniscus-covered and uncovered areas among the OA, contralateral, and normal samples at each sub-tissue zone as well as bulk. The T1-Gd values were found to change significantly with compression of cartilage. More importantly, the magnitude of these changes was highly dependent on the sub-tissue zone and level of strain, with larger increases in the SZ and TZ. The detailed knowledge of the strain-modified T1-Gd profile in cartilage from μ MRI will be useful in characterizing the events in mechanically induced joint diseases and injuries.

ACKNOWLEDGEMENTS:

Y Xia thanks NIH for the R01 grant (AR 52353) and Oakland University for the REF in Biotechnology. The authors are grateful to Ms. Janelle Spann (Michigan Resonance Imaging, Rochester Hills, MI) for providing the contrast agent and lab members for their supports, especially Mr. F. Badar for the normal data.

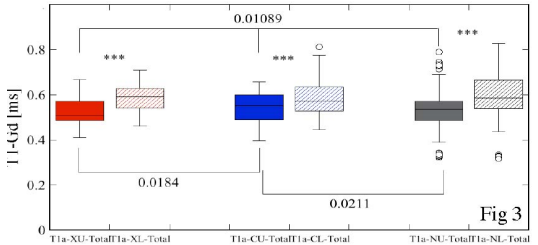
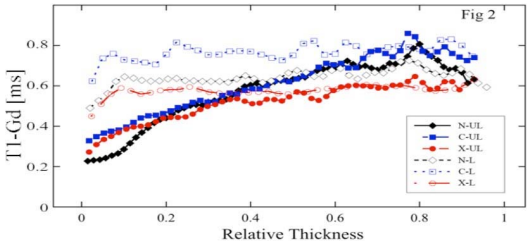
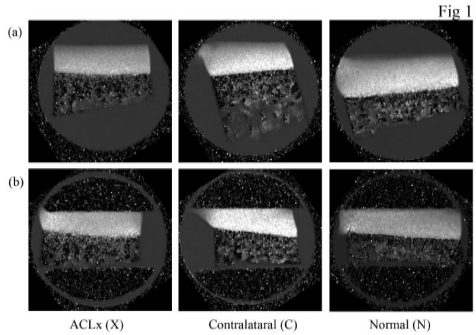


Table 1	Total	SZ	TZ	RZ1	RZ2
T1a-8X-U [ms]	462 482 488 564 538	264 231 259 350 325	307 259 300 417 406	462 424 448 564 539	578 622 625 689 640
T1a-8X-U standard deviation	57 30 30 56 132	34 14 24 77 92	43 22 38 70 123	39 35 45 64 145	74 36 41 76 124
T1a-8C-U [ms]	515 520 510 586 573	274 252 259 334 327	322 307 310 431 408	497 473 470 600 573	659 632 666 704 679
T1a-8C-U standard deviation	46 40 80 33 60	28 15 42 15 50	35 20 63 18 70	38 58 93 31 81	56 55 102 45 68