In Vivo Sodium MRI at 3.0T of Patients with Previous ACL Injury

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INTRODUCTION: Early degenerative changes in articular cartilage leading to osteoarthritis are accompanied by glycosaminoglycan (GAG) depletion in the cartilage matrix. Subjects with prior tears to the anterior cruciate ligament (ACL) may show early development of osteoarthritis [1]. Sodium MRI has been shown to correlate with GAG concentration, and may be useful in detecting and tracking early GAG depletion [2-5]. Sodium MRI is challenging due to relatively low sodium concentrations in biological tissues, and rapid signal decay. Despite these challenges, improved hardware coupled with higher field strengths enable diagnostic-quality sodium MRI *in vivo* in reasonable scan times. Short-TE gradient-spoiled sequences with efficient k-space trajectories are employed to maximize sodium signal and minimize blurring from signal decay. The objective of this study was to investigate cartilage sodium signal in ACL injured knees using sodium MRI.

METHODS: Twenty knees of 10 subjects with previous unilateral ACL tears were imaged in the sagittal plane using a GE Signa Exite 3.0T MRI scanner (GE Healthcare, Milwaukee, WI) and custom quadrature sodium knee coil. Both the injured knee and uninjured knees were scanned. We studied 3 male and 7 female patients (age 21-41) with a range of 2-10 years following ACL injury. All subjects had undergone single bundle ACL reconstructive surgery.

A fast gradient-spoiled sequence using the 3D cones *k*-space trajectory and a rapid (0.64 ms) RF excitation was developed for sodium image acquisition [6]. The centric 3D cones trajectory permits short echo times and achieves very high SNR efficiency, while providing a relatively smooth k-space weighting and making efficient use of gradient resources. Imaging parameters were TR/TE 35/0.6 ms, flip angle 70 degrees, 28 signal averages. Resolution of the sodium MRI acquisition was 1.25 x1.25 x 4 mm with a 21 minute imaging time. B1 maps obtained using a dual-flip angle approach *in vivo* confirmed a flip angle variation of less than 5% across the field of view of the coil.

A 100-mmol-concentration test tube of saline was placed within the coil to correct for signal differences between scans. Conventional proton imaging with a 3D fat-suppressed spoiled gradient echo (3D-FS-SPGR) scan was also obtained to look for cartilage loss. The movement of the subject was minimized between sodium and proton scans to facilitate registration. For each subject, the signal of the sodium in the images was measured using regions of interest in the central regions of the medial and lateral compartments of the femoral and tibial cartilage with OSIRIX [7]. Sodium signal was normalized using the signal from the test tube. Normalized sodium signal was regressed on knee status (normal or surgery) and cartilage region (femur/tibia and medial/lateral), using a PA-GEE regression (STATA, Statacorp).

RESULTS: Knees with a prior ACL injury had significantly lower sodium signal levels (19.6 vs. 22.7, $p < .001$) in all compartments. Medial regions had significantly higher sodium signal levels than lateral ones (21.6 vs. 20.7, $p < .008$) in both injured and uninjured knees. Within-patient correlation was 0.83. Without exception, signal levels were lower in all regions from knees with ACL injury when compared to corresponding regions in the same patient's intact knee (Figure 1). None of the ACL-injured or uninjured knees showed areas of cartilage thickness loss on the proton MRI. Images from knees with a prior ACL repair showed some areas of decreased sodium signal with normal appearing cartilage on proton MRI (Figure 2).

DISCUSSION: Decreased GAG in articular cartilage in osteoarthritis has been shown to be potentially reversible [8]. Proton MRI of cartilage morphology detects cartilage damage at a stage that is widely regarded as irreversible. Our results show that whole knee sodium MRI at 3.0T can detect early changes in articular cartilage sodium signal for patients with previous ACL tears. Sodium signal from articular cartilage correlates directly with GAG content, and *in vivo* sodium MRI is promising for detection of GAG depletion that may occur prior to cartilage loss in osteoarthritis. The ability to detect GAG loss with sodium MRI may help with development of treatments for ACL injury that can be given at a reversible point in the disease process.

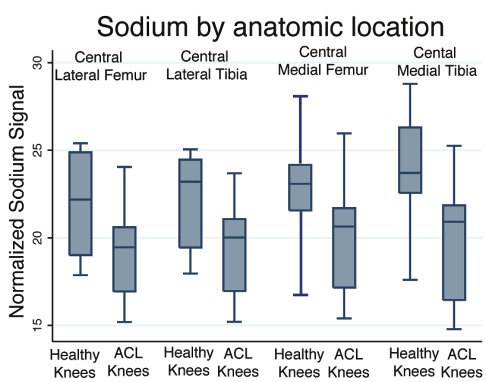

Figure 1: Normalized sodium signal by cartilage region comparing anterior cruciate ligament (ACL) injured knees with the subjects' contralateral healthy knee. Normalized SNR was higher in the healthy knee in all areas ($p < .001$). Signal was also higher in the medial compartment than lateral compartment ($p < .008$).

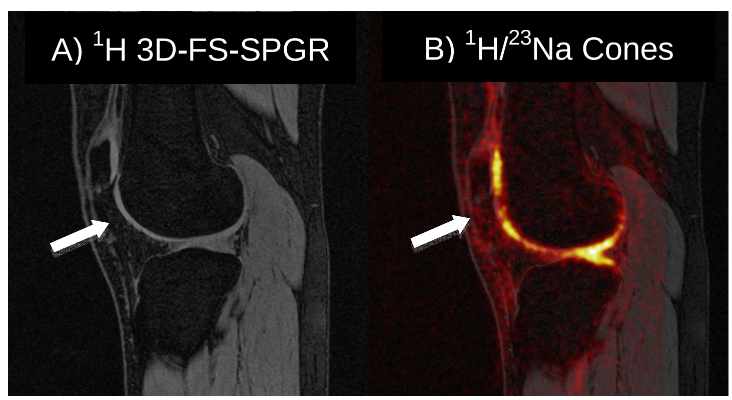

Figure 2: A) Proton spoiled gradient echo image of a patient with a prior anterior cruciate ligament tear in the knee. No cartilage defects were seen. B) Sodium image (1.25 x 1.25 x 4 mm; 21 min acquisition) fused with registered proton image. The sodium signal is decreased in the trochlea (arrow). This may be an area of reversible GAG loss in the cartilage.

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