In Vivo Measurement of ^{23}Na T2* in Human Articular Cartilage at 3T and 7T

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INTRODUCTION: Early degenerative changes in articular cartilage leading to osteoarthritis are accompanied by proteoglycan depletion in the cartilage matrix. Sodium MRI has been shown to correlate with proteoglycan concentration [1-3], and may be useful in detecting and tracking early proteoglycan depletion. This could be helpful for drug discovery in osteoarthritis. Sodium MRI is challenging due to relatively low ^{23}Na concentrations in biological tissues, a rapid bi-exponential signal decay, and a low gyromagnetic ratio (leading to large gradient amplitudes, long scan times, and lower polarization). Despite these challenges, improved coils and gradient 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 often employed to maximize sodium signal and minimize blurring from signal decay [4]. In practice, accurate characterization of sodium T2* decay in a biological tissue of interest is required for sequence parameter optimization, and in some cases can be a marker of underlying physiologic structure. Choice of echo time, readout duration, and flip angle are all informed by transverse signal relaxation characteristics. In this work, MR experiments were performed *in vivo* to measure and compare sodium T2* in human articular cartilage of the knee at both 3T and 7T.

METHODS: A fast gradient-spoiled sequence using the 3D cones k-space trajectory [5] and a rapid (0.64 ms) RF excitation was developed for sodium image acquisition. 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.

The sodium sequence was implemented on a 3T GE Signa Excite whole-body scanner and a 7T GE Excite whole body scanner (GE Healthcare, Waukesha, WI). The patellofemoral cartilage was scanned in five normal knees at *both* 3T and 7T using custom sodium-tuned transmit/receive 3" surface coils. Transmit gain was set manually during prescan to select a flip angle that maximizes signal at the given TR, and was held constant during all acquisitions in a series.

A 3D cartilage ROI for signal measurement was defined by manually segmenting patellar and femoral cartilage from other tissue in each knee series. SNR was then measured across each ROI at each echo time, and a T2* exponential decay curve was fit to the resulting data.

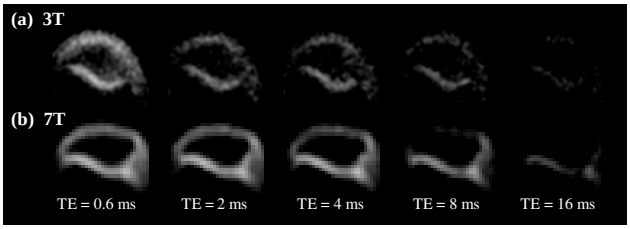

Figure 1: Axial slices from 3D sodium knee scans *in vivo* at multiple echo times at 3T (a) and 7T (b). The bright cartilage signal in the patellofemoral joint is notable, and persists much longer than expected based on previously published sodium transverse relaxation times in articular cartilage. Scan parameters are given in the text.

Scan parameters at 3T were: TR = 50 msec, FOV = 16x16x12.8 cm^3, matrix = 128x128x32 (1.25x1.25x4 mm^3 resolution), 8 msec readout, and 4 signal averages for a total scan time of 4 min 7 sec per acquisition. Acquisitions were repeated at six echo times: TE = 0.6, 1.2, 2.0, 4.0, 8.0, and 16.0 msec.

Scan parameters at 7T were: TR = 50 msec, FOV = 16x16x12.8 cm^3, matrix = 80x80x32 (2x2x4mm^3 resolution), 16 msec readout, and 8 signal averages for a total scan time of 1 min 56 sec per acquisition. Acquisitions were repeated at eight echo times: TE = 0.6, 0.9, 1.2, 2.0, 4.0, 8.0, and 24.0 msec.

TE values in the current sequence implementation were constrained by a minimum echo time of 0.6 msec due to excitation length and hardware limitations. The maximum echo times (16 msec at 3T and 24 msec at 7T) were chosen to preserve reasonable signal levels by considering the T2 and T2* values in articular cartilage previously published (fast T2 relaxation component = 0.7-2.3 msec, slow component = 8-12 msec, T2* at 4T = ~6 msec) [6,7].

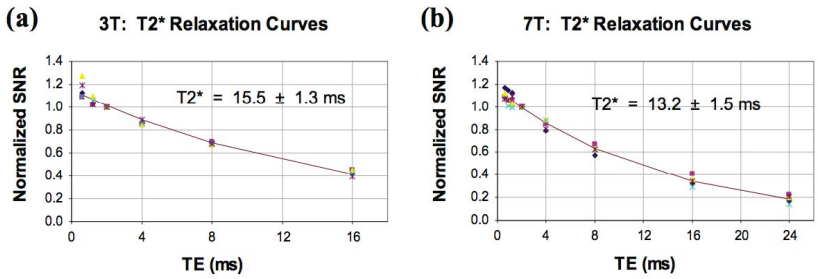

Figure 2: Normalized sodium T2* relaxation curves across articular cartilage ROI on 3D knee scans of healthy volunteers at 3T (a) and 7T (b). A mono-exponential curve was fit to each data series to determine T2* relaxation rates in healthy articular cartilage *in vivo*. Results are consistent across volunteers, and indicate a T2* of 31 ms and 26 ms at 3T and 7T respectively.).

RESULTS: At short echo times, the synovial fluid, skin, and other tissues yield bright sodium signal (Figure 1), necessitating careful segmentation of the cartilage from surrounding tissues. Our image data suggests a sodium transverse relaxation rate in articular cartilage consistent with that published in the literature. The normalized T2* relaxation data is shown in Figure 2 at both 3T (a) and 7T (b), overlaid with the exponential best-fit curve. Signal decay was quite consistent across subjects, and T2* values of 15.5 ± 1.3 msec at 3T and 13.2 ± 1.5 msec at 7T were obtained.

Note that an echo time of 0.6 msec (the shortest employed) is insufficient to capture the fast T2 component in the bi-exponential sodium decay. In the absence of multiple quantum filtering techniques, measurements at ultra-short echo times (TE < 100 μsec) are likely needed to measure the fast transverse decay component. Future work will include adapting our 3D cones sequence to support ultra-short TE for sodium, potentially allowing capture of short-T2 signal.

CONCLUSION: We measured T2* of sodium in patellofemoral cartilage in 5 knees at both 3T and 7T. Results consistently showed a mono-exponential decay with average T2* of 15.5 ms and 13.2 ms at 3T and 7T respectively, consistent with those expected for a long-T2 component based on previously published results. Our long T2* measurements will be important in optimizing pulse sequence parameters for sodium imaging *in vivo* at high fields.

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