

High resolution in-vivo measurement of sodium T1 of human knee cartilage

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Introduction: Sodium MRI is a promising diagnostic technique for assessing cartilage health in-vivo [1]. The measurement of sodium T₁ for tissues in the knee is important for the development of simulations modelling the behaviour of sodium and the creation of optimized pulse sequences. T₁ differences can be used to suppress fluid signal (akin to FLAIR for ¹H) as has been shown for the brain [2] and knee [3,4]. Previous work has reported measurements of T₁ for bovine [3,5,6] and ex-vivo human cartilage at 7T [4]. However, there are no human in-vivo measurements. Isolating T₁ in-vivo for fluid sacs and thin cartilage requires good resolution inversion-recovery images that can be difficult to obtain due to rapid T₂ decay. The purpose of this abstract is to measure sodium T₁ in-vivo for cartilage, blood, and synovial fluid. We used the T₁ values to obtain a high-resolution fluid-suppressed image of human knee cartilage.

Methods: In five healthy subjects, inversion-recovery (rectangular π pulse, TI = 3,7,15,25,40,70 ms) sodium imaging was performed on a 4.7T MRI system, with a custom sodium birdcage coil. Twisted projection imaging (p=0.17, projections=3000, readout/TR/TE=12.95/(150+TI)/0.261ms, N_{av} = 1, res~1.5 mm iso) was used to obtain an image with a 120 mm field of view. Total imaging time for all acquisitions was 42 minutes. The acquired signal was regridded into an 80x80x80 matrix. The images were co-registered and the image data was fit to $M=P_1(1+P_2\exp(-TI/T_1))$ to create a T₁ map. In the fit, M is the signal magnitude attained with inversion time TI; P₁ is the initial magnitude of the signal; P₂ accounts for incomplete inversion from relaxation due to the short T₂. The patellar cartilage, femoral/tibial cartilage, popliteal and synovial fluid ROIs were identified on the T₁ map. The timing for minimal fluid signal was identified from the inversion recovery curves, and used to obtain a fluid-suppressed sodium image (p=0.17, projections = 3000, readout/TR/TI/TE=12.95/100/24/0.261ms, N_{av} = 3, total time = 18.9 min, res~ 1.5 mm iso).

Results/Discussion: Fits to the inversion curves (Figure 1) were excellent for all subjects and tissues ($r^2 > 0.9999$) and yielded individual T₁ maps (Figure 2). The T₁'s of the patellar and femoral/tibial cartilage (Table 1) were similar, ~22 ms, whereas the T₁'s for both the popliteal and synovial fluid were longer at ~47 ms. Twisted-projection imaging for the readout enabled the acquisition of the range of inversion times within one scanning session. Our sodium T₁ values are a bit smaller than those of ex-vivo human cartilage (26±6 ms) measured at 7T [4]. The T₁ value for both the fluids was slightly less than the T₁ of saline (53 ms) at 4.7T [2]. This may be due to a difference in composition between saline and synovial fluid or possibly partial volume effects given the small tissue structures in the knee.

Table 1	Na T ₁ (ms)	P ₂
Patellar Cartilage	21.8±2.0	-1.74±0.13
Femoral/Tibial Cartilage	22.2±2.3	-1.73±0.02
Popliteal Blood	46.6±4.0	-1.57±0.07
Synovial Fluid	46.9±3.3	-1.40±0.04

The fluid suppressed sodium image, with a nominal resolution of 1.5 mm isotropic, demonstrated sharp delineation of the patellar cartilage as well as the thin femoral/tibial cartilage (Figure 3). When compared to previous fluid suppression techniques for sodium which produced images with a resolution of 3.6 mm isotropic in 17 min at 7T [4], twisted projection yielded superior images. This may assist in accurate quantification of cartilage sodium in-vivo and permit the non-invasive evaluation of cartilage degeneration.

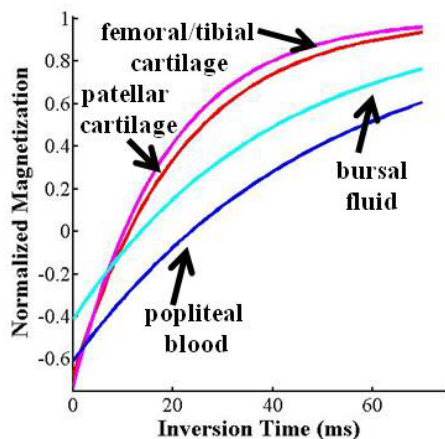


Figure 1: Sodium T₁ relaxation curves for regions of interest highlighting similarities in cartilage and slower recovery for fluid.

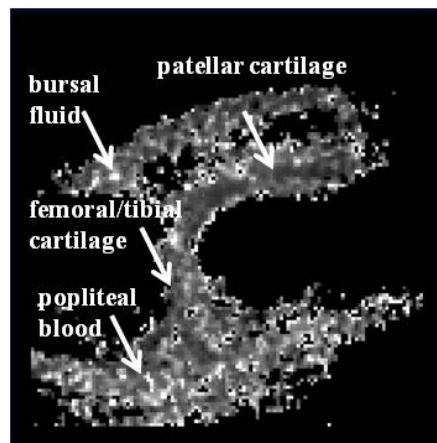


Figure 2: T₁ map identifying four regions of interest.

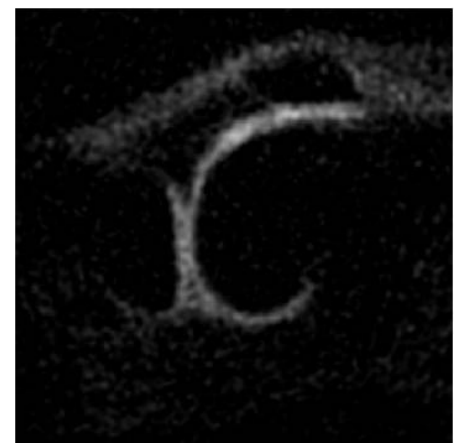


Figure 3: Sagittal fluid suppressed sodium image (TI = 24 ms, total time = 18.9 minutes, nominal resolution = 1.5 mm isotropic) of human knee.

References: [1] Wheaton, Radiology 231:900(2004) [2] Stobbe et. al, MRM 54:1305(2005) [3] Rong, JMR 193:207(2008) [4] Madelin, JMR 207:42(2010) [5] Borthakur, Radiology 224:598(2002) [6] Jelicks, JMIR 3:565(1993)