Validation of adiabatic $T_1\rho$ and $T_2\rho$ mapping of articular cartilage at 3T

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TARGET AUDIENCE: Researchers and clinicians aiming to apply quantitative MRI techniques in osteoarthritis research.

PURPOSE: To validate adiabatic $T_1\rho$ ($AdT_1\rho$) and adiabatic $T_2\rho$ ($AdT_2\rho$) sequences for quantitative measurements of cartilage with a 3 T clinical scanner.

METHODS: $AdT_1\rho$ and $AdT_2\rho$ sequences[1,2] were tested in a 3 T clinical system (Siemens Skyra) in combination with a 15 channel knee coil for signal transmission/reception. Adiabatic $T_1\rho$ experiments, were performed as described previously[2,3] using a preparation block which consisted of a train of 0, 4, 8, 12 and 16 adiabatic full passage (AFP) hyperbolic secant pulses of the HSn family, here HS4. For adiabatic $T_2\rho$ the AFP pulses were placed between two adiabatic half passage pulses (AHP). The preparation block was followed by a gradient recalled echo (FLASH) readout (TR / TE = 20 s / 3.75 ms, 15° flip angle, 256 x 256 matrix, 7 mm slice thickness, FOV = 120 x 120 mm^2, 2 averages). For both $AdT_1\rho$ and $AdT_2\rho$ the RF peak amplitude was γB_{1max} = 800 Hz; R=10 and pulse duration 6 ms was used, which resulted in the BW = 1.6 kHz. Longitudinal and transverse relaxation time constants in the rotating frame were calculated by mono-exponential fitting of the signal intensity decays on a pixel-by-pixel basis. Actual flip angle maps were calculated to evaluate B_1 homogeneity. Nine agarose gel nickel-doped phantoms were prepared with relaxation times within biological tissue range (T_1 = 400 - 2600 ms, T_2 = 40 – 170 ms). Reproducibility was assessed by calculating the coefficient of variation (CV %) of three measurements repeated within one month. Six chondroitin sulfate (CS), the main proteoglycan constituent (0.0, 2.0, 4.0, 6.0, 8.0, 9.0 % w/w, pH 7.1), tubes were prepared. $R_1\rho$ (=$1/T_1\rho$) and $R_2\rho$ (=$1/T_2\rho$) were studied as a function of CS concentration. Finally, the feasibility of $AdT_1\rho$ and $AdT_2\rho$ measurements in the human knee joint was demonstrated.

RESULTS: B_1 mean error in the region of interest was 4.8 % (Fig. 1a inset left), indicating good B1 homogeneity. $R_1\rho$ and $R_2\rho$ measured with HS4 pulses were linearly dependent on agarose concentration (Fig. 1a and 1b). Reproducibility as indicated by CV% was 0.77 % and 2.0 % for $AdT_1\rho$ and $AdT_2\rho$, respectively. $R_1\rho$ and $R_2\rho$ were dependent on chondroitin sulfate concentration and on the inversion bandwidth (Fig. 1c). Figures 1d and 1e show $T_1\rho$ and $T_2\rho$ maps of human knee cartilage.

DISCUSSION: Previously, adiabatic $T_1\rho$ and adiabatic $T_2\rho$ have been applied in preclinical studies at different field strengths and their ability to probe slow molecular motion has been shown[1,2]; former *in vitro* studies have observed high sensitivity of $AdT_1\rho$ and $AdT_2\rho$ to animal and human cartilage degeneration at 9.4 T[3-5]. At 3 T the sequences showed very good reproducibility, higher for $AdT_1\rho$ compared to $AdT_2\rho$. $R_1\rho$ and $R_2\rho$ were very sensitive to variations in both agarose and CS. Finally, the sequences were adapted for quantitative measurement of articular cartilage and then successfully applied *in vivo*.

CONCLUSION: Phantom experiments with hyperbolic secant pulses (HS4) revealed excellent accuracy of the sequences and strong dependencies of $R_1\rho$ and $R_2\rho$ on agarose and chondroitin sulfate concentration, which are relevant for cartilage. The findings demonstrate that adiabatic $T_1\rho$ and adiabatic $T_2\rho$ techniques are promising tools for in vivo cartilage imaging at 3T.

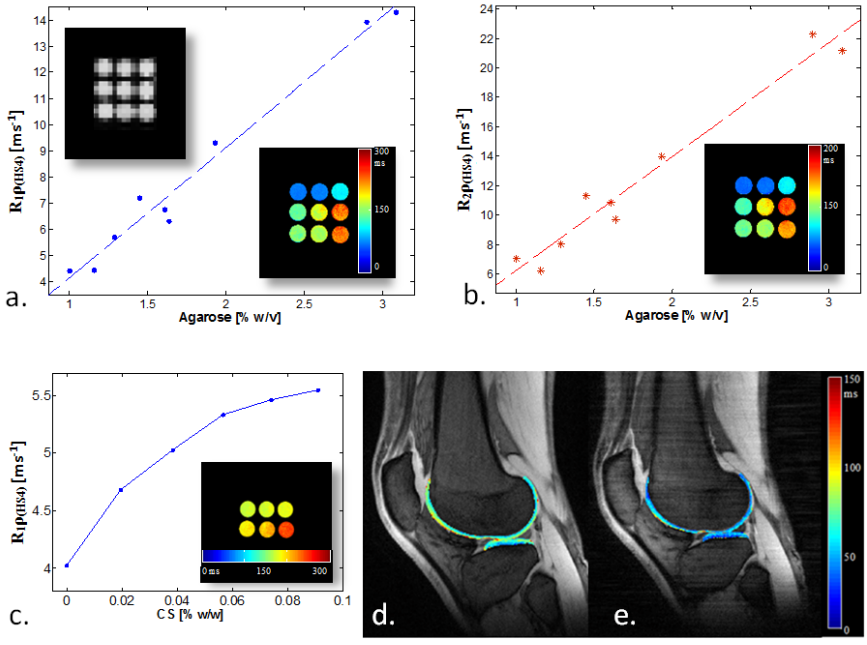

Figure 1. (a) $R_1\rho$ vs. agarose concentration (inset left; actual flip angle map; inset right: $R_1\rho$ map). (b) $R_2\rho$ vs. agarose concentration (inset: $T_2\rho$ map). (c) $R_1\rho$ vs. CS concentration (inset: $T_1\rho$ map). (d) $T_1\rho$ map of human cartilage. (e) $T_2\rho$ map of human cartilage.

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