Optimization of adiabatic $T_{1\rho}$ and $T_{2\rho}$ for quantification 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 optimize adiabatic $T_1\rho$ ($AdT_1\rho$) and adiabatic $T_2\rho$ ($AdT_2\rho$) sequences for *in vivo* quantitative measurements of articular cartilage at 3 T.

METHODS: $AdT_1\rho$ and $AdT_2\rho$ sequences[1,2] were used with a 3 T clinical system (Siemens Skyra) in combination with a 15 channel knee coil. Adiabatic $T_1\rho$ measurements were performed as described previously[3,4] using a preparation block consisting of a train of 0, 4, 8, 12 and 16 adiabatic full passages (AFP) hyperbolic secant pulses of the HSn family (here HS4) followed by a gradient recalled echo (FLASH) readout (TR = 2.5 – 6 s, TE = 3.36 ms, 256 x 256 matrix, 3 mm slice thickness, FOV = 180 x 180 mm^2). For adiabatic $T_2\rho$ the AFP pulses were placed between two adiabatic half passage pulses (AHP). RF peak amplitude was γB_{1max} = 800 Hz (maximum achievable with the selected coil). For the FLASH readout, factor 2 GRAPPA, 23 segments per preparation and partial phase encoding were used to reduce the scanning time to be clinically suitable (about 2 min 20 s per slice). Three human knees were imaged, two from asymptomatic healthy volunteers and one from a patient with early radiographic Osteoarthritis (KL=1). $T_1\rho$ and $T_2\rho$ maps were calculated and the experiments were repeated with different repetition time (TR) and flip angle of the readout sequence. Optimal parameters were determined by evaluating the relaxation time maps and by minimizing the scanning time and power deposition and maximizing the image quality in terms of signal to noise ratio, stability and absence of artifacts. Flip angle maps were calculated to evaluate the B_1 homogeneity.

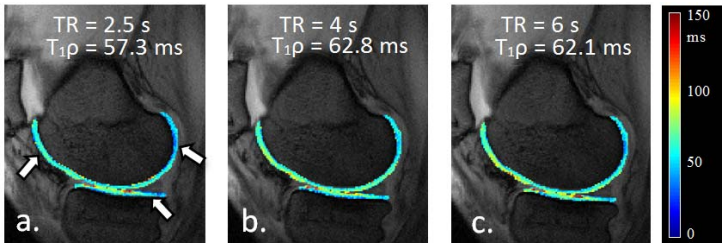

Figure 1. $T_1\rho$ maps with TR 2.5 (a), 4.0 (b), 6.0 s (c). $T_1\rho$ was dependent on TR (see white arrows).

RESULTS AND DISCUSSION: The $AdT_1\rho$ and $AdT_2\rho$ sequences were evaluated with a 3 T clinical system and the optimized parameters were estimated for quantitative *in vivo* imaging of articular cartilage. TR has to be kept as short as possible to minimize the acquisition time, but must be long enough to avoid steady-state and to mitigate the specific absorption rate (SAR). Below 4 s the relaxation was TR-dependent (Fig. 1a), suggesting that the signal reduction was rather due to partial saturation. $T_1\rho$ maps acquired with TR 4 s or longer showed no substantial variations in relaxation times (Fig. 1b and 1c). Based on the results the shortest suitable TR was 4 s. The optimal flip angle was chosen in order to get the best SNR possible preventing the aliasing artifacts occurring at larger angles. SNR at 15 degrees was almost doubled compared to 10 degrees (SNR ~ 40-50) but approximately the same at 30 degrees (SNR ~ 85-90), thus 15 degree flip angle was selected as the optimum. B_1 mean error in the region of interest was 13.6 % (Fig. 2a inset), indicating a mild B_1 inhomogeneity, which can be compensated with the adiabatic pulses. $AdT_2\rho$ maps revealed similar dependence on TR and T_p (data not shown). Several *in vitro* studies have reported high sensitivity of $AdT_1\rho$ and $AdT_2\rho$ to cartilage degeneration at 9.4 T[3-5]. Relaxation times of the one patient were different from what measured in healthy controls. The preliminary data shows feasibility of $AdT_1\rho$ and AdT2ρ measurements at 3T within acceptable scanning times for human studies aiming at distinguishing between normal and early osteoarthritis cartilage (Fig. 3).

CONCLUSION: This study reports the optimal settings of these sequences on a 3 T MRI clinical system for knee imaging. The findings indicate that adiabatic $T_1\rho$ and adiabatic $T_2\rho$ are suitable for *in vivo* quantitative assessment of articular cartilage at 3 T. The clinical potential of these techniques in detecting early osteoarthritis will be investigated in subsequent studies.

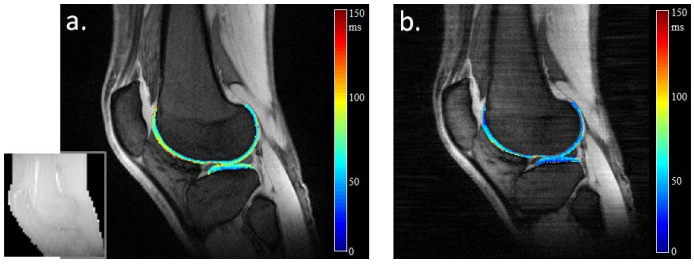

Figure 2. $T_1\rho$ (a) and $T_2\rho$ (b) map of articular cartilage of a representative asymptomatic subject (inset: B1 map)**.**

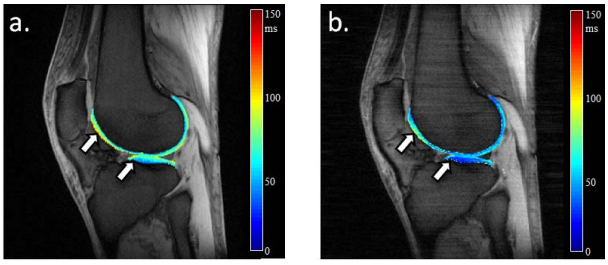

Figure 3. $T_1\rho$ (a) and $T_2\rho$ (b) maps of articular cartilage from a patient with early radiographic Osteoarthritis (KL=1). In anterior femur and tibia relaxation times were found 15-25% longer compared to healthy control (see white arrows).

REFERENCES. 1. Michaeli et al. MRM 2005, 53:823–9. 2. Michaeli et al. JMRI 2006, 181:135–47. 3. Rautiainen et al. MRM 2014, doi: 10.1002/mrm.25401. 4. Rautiainen et al. OAC 2014, 22(10):1444-522. 5. Ellermann et al. MRI 2013, 31:1537-43.