7 Tesla MR - initial results on T2 and T2* mapping of healthy articular cartilage and cartilage repair tissue

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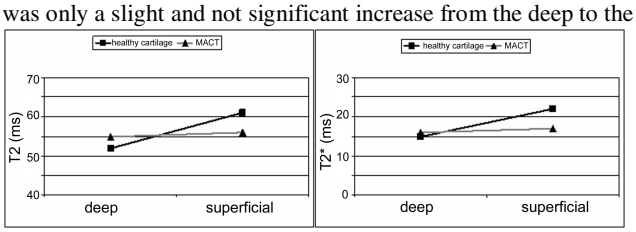
Introduction: High field (3.0T) and ultra-high-field whole body systems (7.0T) have high potential in future human in-vivo MRI, mainly availing of the higher signal-to-noise ratio of stronger magnets (1). In research applications and even in an increasing number of clinical utilization on the musculoskeletal system, the step from 1.5T to 3T MRI has been done within the last years. Based on the higher signal-to-noise ratio leading to potentially faster scan times, a rapid improvement for in-vivo implementation on articular cartilage is given. Especially biochemical MRI, utilizing techniques as T1 mapping based on delayed Gadolinium enhanced MRI of cartilage (gGEMRIC), T1 rho relaxation mapping and T2 mapping are trying to visualize the composition of articular cartilage. Cartilage T2 reflects the interaction of water and the extracellular matrix on a molecular level, particularly changes in water and collagen content and tissue anisotropy (2). In healthy articular cartilage, an increase of T2 values from deep to superficial cartilage layers can be observed (3). Histological validated animal studies have been shown this zonal increase as a marker of hyaline or hyaline like cartilage structure after cartilage repair procedures within the knee (4). To visualize this zonal variation in-vivo, high in-plane resolution and relatively short scan time would be important. This could be achieved by high-field and even better by ultra-high-field MRI. Besides standard multi-echo spin-echo (SE) T2 relaxation, T2* mapping with its possible short scan time seems to offer a potential alternative and has been shown reliable results in cartilage imaging (5). In recent studies, T2* relaxation was validated and correlated to SE-T2 at 3T MRI, showing comparable information of articular cartilage within the knee as well as zonal variation in healthy cartilage, however over all lower T2* values (6). Previous measurements of cartilage T2 mapping within the knee in healthy volunteers at 7T MRI demonstrate its feasibility as well as similar results compared to 3T (7). However to the best of our knowledge no in-vivo T2 and T2* measurements have been demonstrated at 7T and no initial results on patients after cartilage repair are available.
Thus the aim of our study was to show the feasibility of T2 and T2* relaxation measurements at 7T MRI as well as to express its potential in an initial patient study in patients after matrix associated autologous chondrocyte transplantation (MACT) within the knee.

Material and Methods: MR imaging was performed on a whole-body 7.0 T MR scanner (Siemens, Erlangen, Germany) using a dedicated CP knee coil. The protocol for volunteer and patient measurements was identical and consisted of a multi-echo spin-echo (SE) sequence using 6 echoes for standard T2 mapping, a GRE sequence using 6 echoes for assessment of the T2* maps and a morphological PD SPACE sequence. T2 relaxation times were obtained from T2 maps reconstructed using a sagittal SE acquisition with a repetition time (TR) of 2000 ms and six echo times (TE) of 15.5ms, 31ms, 46.5ms, 62ms, 77.5ms and 93ms. Field of view (FoV) was 160x160 mm, pixel matrix 640x640, voxel size 0.6x0.6x3.0mm; 3 slices; acquisition time (TA) was 6:39 minutes. T2* maps were conducted using a GRE acquisition with TR of 85ms and TE of 4.4ms, 8.5ms, 11.6ms, 15.7ms, 19.5ms and 23.6ms. Fov, matrix and voxel size were kept identically for better comparability; 3 slices; TA 2:45 minutes. Fat saturated PD SPACE was scanned with a TR of 2200ms and TE 24ms. FoV was 160x160mm, pixel matrix 220x256 and voxel size 0.6x0.6x0.6mm; 144 slices; TA 13 min 39 sec. PD SPACE was prepared on the whole knee, SE-T2 and T2* were scanned sagittal over one femoral condyle. 12 healthy volunteers with no clinical symptoms or history of knee pain (Mean age 26.7±3.4years) and 4 patients (Mean age 38.0±14.0years) 29.5 ± 15.1 months MACT were enrolled. T2 and T2* maps were obtained using a pixel wise, mono-exponential non negative least squares (NNLS) fit analysis. Regions of interest (ROI) within the weigth bearing zone of the femoral condyle were manually drawn. ROIs covering full thickness of cartilage were divided into a deep and superficial aspect. As in patients cartilage repair areas were located within the weight bearing zone of one femoral condyle, ROIs of healthy appearing cartilage were also placed within the weight bearing zone. Statistical evaluation was done by analyses of variance using a three way ANOVA. A P value less than 0.05 considered a statistically significance.

Results: Global mean T2 relaxation for healthy volunteers was 56.3±15.2ms; global mean T2* value of healthy volunteers was 19.7±6.4ms. Concerning zonal variation of T2/T2* values, for both a significant increase from deep (T2: 54.2±17.5; T2*: 16.9±6.1) to superficial (T2: 58.3±14.4; T2*: 22.5±7.7) was observed. Within healthy seen cartilage sites of MACT patients, adequate values could be found for T2 (56.6±13.2) and T2* (18.6±5.3), also showing a significant increase from deep to superficial. Within the cartilage repair area after MACT, global mean values showed no difference with 55.9±4.9 for T2 mapping and 16.2±6.3 for T2* mapping. However concerning the zonal variation, there was only a slight and not significant increase from the deep to the superficial zone (Figure 1 – black line healthy cartilage; grey line MACT).



Discussion: T2 as well as T2* mapping within healthy and reparative articular cartilage seems to be possible at 7T MRI. Additional zonal variation of healthy hyaline cartilage is visible at 7T. As the zonal evaluation still is limited by insufficient in-plane resolution, in future studies optimized protocol as well as multi-channel coils together with increased signal at ultra-high-field MRI can prepare a next step in biochemical cartilage imaging.

References: 1. Vaughan JT et al. MRM 2001;46(1):24-30. 2. Mosher et al. Semin Musculoskelet Radiol 2004;8(4):355-368. 3. Smith et al. JMRI 2001;14(1):50-55. 4. White LM et al. Radiology 2006;241(2):407-414. 5. Murphy et al. Skeletal Radiol 2001;30(6):305-311. 6. Hughes T et al. ISMRM, Berlin 2007. 7. Pakin SK at al. Acad Radiol 2006;13(9):1135-1142.

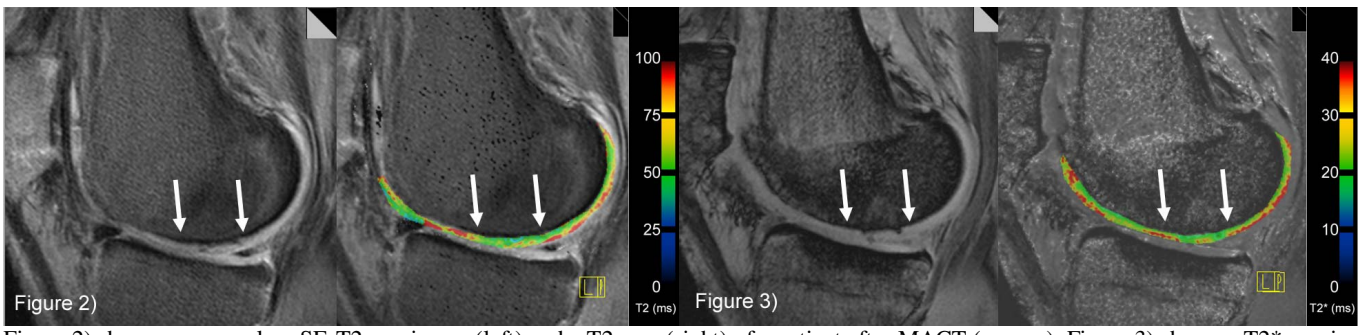


Figure 2) shows an exemplary SE-T2 raw image (left) and a T2 map (right) of a patient after MACT (arrows). Figure 3) shows a T2* raw image (left) and T2* map (right) of the same patient.