Magnetization Transfer of Cartilage and Cartilage Repair Tissue at Ultra-High Fields Using SSFP

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Introduction. Research and development of ultra-high-field whole body systems (7.0T and above) is progressing rapidly. Particularly, cartilage imaging benefits from improved image quality, contrast, and resolution at higher field strengths, since higher resolution may improve diagnostic accuracy and confidence (1). Recent studies have corroborated the clinical potential of biochemical imaging to visualize the constitution of cartilage repair tissue (2). Here, magnetization transfer (MT) is evaluated for the assessment of zonal differences in articular cartilage and its ultra-structure. First, the feasibility of high resolution MT at 7T is demonstrated using MT sensitized steady-state free precession (MT-SSFP) (3). Thereafter, MT is evaluated for normal and for cartilage repair tissue, revealing significant differences between healthy and affected articular cartilage. In summary, MT SSFP can successfully be used for the assessment of cartilage repair and areas of intact hyaline cartilage at 7T.

Methods. Measurements were performed on a Magnetom 7T whole body system (Siemens Medical Solution, Erlangen, Germany). 3D MT images were generated using an SSFP-FID variant of balanced MT-SSFP (3), in order to circumvent issues from local susceptibilities. Sensitizing to MT is achieved from RF pulse modulation (Fig. 1). In contrast to balanced SSFP, SSFP-FID is affected from changes in TR that arise from RF pulse modulations. Within the applied range of 7 to 10 ms, however, corruption of MTR values by TR variation is below 1-2%. MT-weighted SSFP images were acquired with TE/TR=3.0/6.9ms (TRF=600µs), whereas MT-free images based on TE/TR=4.7/10.3ms (TRF=400µs). Forty slices were acquired within 3.5 (MT-weighted) and 5 (MT-free) minutes with 280µm×280µm× 3000µm resolution and the signal (S) was evaluated based on the MT ratio (MTR), i.e. MTR = 100%·($S_0 - S_{MT}$)/S_0, expressed in percental units [%]. The flip angle and the pixel bandwidth was fixed to 30° and 320Hz, respectively. Sagittal (femoral condyle aligned) and axial (patella aligned) images of articular cartilage were acquired from five healthy volunteers (mean age: 28.2±3.6; 4m, 1f). Matrix associated autologous chondrocyte implantation (MACI) was evaluated from sagittal (medial femoral condyle aligned) images in four patients (mean age: 38±14; 3m, 1f) 29.5±15.1 months after therapy. Regions of interest (ROIs) for cartilage repair and healthy control were manually drawn by an experienced senior musculoskeletal radiologist in consensus with an orthopedic surgeon. The ROIs had to cover the full thickness of cartilage repair/control cartilage. For further evaluation on the zonal variation, the ROIs were divided into two equal sized deep (suffix: 'd') and superficial (suffix: 's') regions. Mean values of ROIs within the cartilage repair tissue sites were compared to mean values within control cartilage sites. SPSS was used for data analysis and differences in P values of less than 0.05 were considered as statistically significant. A three way analysis of variance (ANOVA) with random factor was used to considering the fact that different measurements within each patient were performed. The trend between cartilage layers was analyzed based on a three way ANOVA with random effects within two repeated measurement.

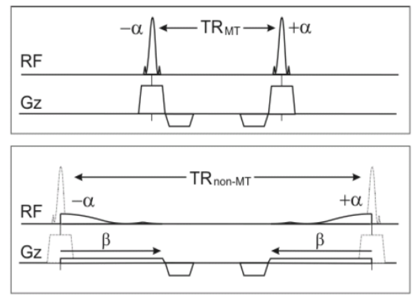

Fig.1 (a) MTR SSFP framework. RF pulse modulation is used to modulate MT effects (3).

Results & Discussion. An illustrative sample image of MT quantification is displayed in Fig. 2. Typically, MTR values in the range of 20% were found for healthy articular cartilage. For normal appearing cartilage, mean MTR values of 20.3±5.1 (MTR_d=18.1±6.3, MTR_s=22.2±5.5) for the sagittal evaluation of the femoral condyle and mean MTR values of 17.8±5.9 (MTR_d=15.8±7.2, MTR_s=19.7±7.4) for the axial images of the patella were found. For repair tissue (MACI), mean sagittal MTR values of 11.3±4.5 (MTR_d=10.2±3.0, MTR_s=12.3±7.4), being in contrast to the internal healthy reference mean MTR values of 19.5±8.4 (MTR_d=17.1±8.2, MTR_s=21.9±11.7). As a result, a statistical significant difference between healthy and repair tissue (MACI) was found for the mean MTR (p=0.014), as well as for deep (p=0.023) and superficial (p=0.042) articular cartilage. However, no statistically significant difference between sagittal and axial MTR evaluations in healthy cartilage was found (mean: p=0.100; deep: p=0.179 and superficial: p=0.164). Furthermore within the healthy volunteers a significant trend from deep to superficial aspects was found for the axial measurements of the patella (p=0.017) and the sagittal measurements of the femoral condyle (p=0.003). Generally, MTR values are considerably reduced as compared to GRE MT measurements at low-fields, as a result of the low flip angle (α=30°) used due to SAR limitations. Nevertheless, it is demonstrated that MT SSFP can successfully be used to assess articular cartilage and cartilage repair, as well as zonal differences.

Conclusion. It was given evidence that MT can successfully be used for the assessment of cartilage repair and areas of intact hyaline cartilage. As a result, MT SSFP may evolve as a valuable tool for the evaluation of cartilage damage in a clinical setup, providing short acquisition times and high SNR, especially at ultra-high fields.

References. (1) Masi JN et al. *Radiology* **236** (2005). (2) Trattnig S et al. *JMRI* **26** (2007). (3) Bieri O et al. *MRM* **58** (2007).

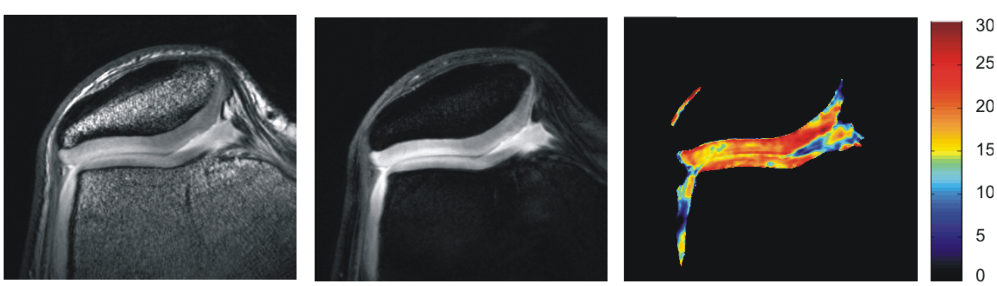

Fig. 2: Illustrative sample images of 3D cartilage SSFP-MT at 7T in a healthy young volunteer showing the patella of the knee joint MT-weighted SSFP (left), MT-free SSFP (middle), and corresponding MTR image (right). Zonal differences in cartilage microstructure are clearly depicted by MTR SSFP.