A COMPREHENSIVE 7 TESLA MRI PROTOCOL FOR QUANTITATIVE (T1-, T2-, T2*-MAPPING) AND MORPHOLOGICAL HIP CARTILAGE IMAGING

Andrea Lazik[1,2], Jens M Theysohn[1], Stephan Orzada[2], Harald H Quick[2,3], and Oliver Kraff[2]

[1]Department of Diagnostic and Interventional Radiology and Neuroradiology, University Hospital Essen, Essen, NRW, Germany, [2]Erwin L. Hahn Institute for Magnetic Resonance Imaging, University Duisburg-Essen, Essen, NRW, Germany, [3]High Field and Hybrid MR Imaging, University Hospital Essen, Essen, NRW, Germany

Target audience: Clinicians interested in cartilage imaging, scientists working at ultra-high field systems with interest in functional musculoskeletal MRI.

Purpose: MRI plays an important role in the non-invasive staging of osteoarthritis, as well as in the diagnosis of focal cartilage lesions and their postoperative follow up. Traditional imaging techniques can provide information about cartilage morphology, whereas quantitative imaging methods are able to show subtle changes in cartilage composition before structural changes appear. Among them, T2- and T2*-mapping techniques provide information about the collagen structure[1]. Delayed gadolinium enhanced MRI of cartilage (dGEMRIC), a T1-mapping technique after intravenously contrast agent administration, provides information about the content of glycosaminoglycanes in cartilage[2]. Because of the thin cartilage layer and the spherical shape of the hip joint, a high spatial resolution is needed for adequate cartilage imaging. Together with improved tissue contrast and shorter acquisition times, 7 Tesla (T) MRI is expected to improve diagnostic accuracy.

The purpose of this study was to evaluate a comprehensive hip cartilage imaging protocol at 7T MRI, including morphological and quantitative imaging techniques in healthy volunteers, and to apply this protocol in patients after acetabular autologous chondrocyte transplantation (ACT).

Methods: MRI: Hips of 11 healthy volunteers (5 female, 6 male, 21 – 46 years, BMI 22.5 +/- 3.1 kg/m²) were examined with 7T MRI (Magnetom 7T, Siemens Healthcare Sector, Germany) using an 8-channel transmit/receive coil. For morphological imaging, high-resolution DESS (0.7 mm^3 isotropic, TA 5:12 min) and T1 VIBE (0.4 x 0.4 x 0.8 mm^3, TA 5:57 min) sequences were acquired. Multi-contrast sequences with 5 echoes each were used for T2- and T2*-mapping (0.5 x 0.5 x 2.5 mm^3, TA 4:53 resp. 2:06 min), and a dual-flip angle technique for T1-mapping (0.4 x 0.4 x 2.0 mm^3, TA 5:13 min). All sequences were acquired prior to and after contrast agent administration due to a standard dGEMRIC-protocol[2] (0.2 mmol/kg body weight Gd-DTPA^{2-} intravenously, ½ hour of walking, ½ hour of rest). Accurate and reproducible scan-rescan conditions were monitored with a fast B1-mapping technique (DREAM). Up to now, this protocol was applied in three patients after ACT.

Evaluation: A qualitative analysis using a Lickert scale evaluated the delineation of acetabular and femoral cartilage (1 = not delineable … 4 = fully delineable). Contrast ratios of cartilage and subchondral bone, as well as of cartilage and joint fluid were calculated. Relaxation times were measured in 5 acetabular and 5 femoral regions by manually placing regions of interests (mean size 419 px (T1) resp. 217 px (T2/T2*)) in the automatically calculated maps (Syngo MapIt, Siemens Healthcare Sector, Germany) in the native ($T1_0$, $T2_0$, $T2^*_0$) and contrast enhanced ($T1_{Gd}$, $T2_{Gd}$, $T2^*_{Gd}$) sequences.

Statistics: Mean values with standard deviations were calculated for all parameters. Differences between contrast-ratios of unenhanced (CR_0) and contrast-enhanced (CR_{Gd}) DESS- and T1-sequences were calculated using Student´s t-test. The concentration of Gd-DTPA^{2-} was calculated ($T1_{delta} = 1/T1_{Gd} - 1/T1_0$) and compared to $T1_{Gd}$ using Pearson´s correlation. Differences between pre- and postcontrast T2- and T2*-values were evaluated by Student´s t-test, and correlations of them by Pearson´s correlation.

Results: Morphological imaging in volunteers: Contrast ratios were significantly increased in all 11 volunteers after contrast agent administration with the highest differences between cartilage and joint fluid in T1 VIBE ($CR_0 = 0.11$, $CR_{Gd} = 0.32$, $p < 0.001$). Concordantly, delineation of acetabular and femoral cartilage raised from hardly delineable (2.1 +/- 0.7) to almost predominantly delineable (2.8 +/- 0.4) in the qualitative analysis (Figure 1).

T1 in volunteers: Qualitative delineation of acetabular and femoral cartilage was better in $T1_{Gd}$ compared to $T1_0$ (2.5 +/- 0.7 vs. 1.8 +/- 0.6). Mean values of $T1_0$ were 1508 +/- 647 ms for acetabular, and 1499 +/- 633 ms for femoral cartilage. Mean values of $T1_{Gd}$ were 911 +/- 449 ms for acetabular, and 950 +/- 455 ms for femoral cartilage. There was a high correlation between T_{delta} and $T1_{Gd}$ for both regions ($p < 0.001$).

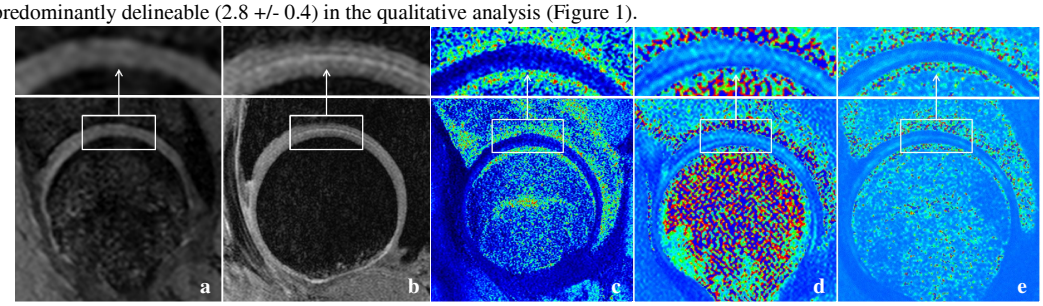

Figure 1: Sagittal 7T MRI of the hip of a healthy volunteer with enlarged views of central cartilage above: (a) DESS, (b) contrast enhanced T1 VIBE, (c) T1-map in dGEMRIC-technique, (d) T2-map, (e) T2*-map.

T2 and T2* in volunteers: Delineation of acetabular and femoral cartilage was equal prior to and after contrast agent administration with excellent values (T2: 2.9 +/- 0.8 points, T2*: 3.4 +/- 0.5 points). Mean values of $T2_0$ and $T2_{Gd}$ did not differ significantly as expected (acetabular: 44.4 +/- 8.2 ms vs. 43.2 +/- 7.7 ms, $p = 0.10$; femoral: 40.7 +/- 7.9 ms vs. 40.1 +/- 6.7 ms, $p = 0.35$). Also $T2^*_0$ and $T2^*_{Gd}$ showed a significant correlation (acetabular: 15.2 +/- 4.1 ms vs. 14.5 +/- 3.8 ms, $p < 0.001$; femoral: 15.3 +/- 3.8 ms vs. 14.7 +/- 3.8, $p < 0.001$). Furthermore, there was a high correlation between the values for T2 and T2*, both prior to and after contrast enhancement ($p < 0.001$).

Patients: Cartilage transplants were clearly delineable in the morphological sequences. For delineation of cartilage transplants in the relaxation-time maps, a correlation together with the morphological sequences was necessary in part, as known from 3T studies[3] (Figure 2).

Discussion: The high spatial resolution of the evaluated sequences at 7T yielded a good to excellent delineation of acetabular and femoral cartilage, which is essential for the evaluation of cartilage pathologies. To implement dGEMRIC in clinical routine, pre-contrast scans are normally omitted at 3T[4,5]. Our results with the high correlation between T_{delta} and $T1_{Gd}$ show, that unenhanced scans might be dispensable at 7T as well. Comparable values of T2- and T2* relaxation times published in 7T studies of the knee[6], as well as slightly higher values published in 3T studies of the hip[7,8] indicate the accuracy of the applied methods. Finally, the expected high correlation of T2- and T2*-values prior to and after contrast agent administration makes these techniques able to be implemented in a dGEMRIC protocol. The contrast ratios of the applied morphological sequences regarding cartilage delineation were improved by contrast agent administration. It can be expected that other pathologies as i.e. labral tears, will also be better visible in contrast enhanced scans. First examinations of patients after ACT with the established protocol show promising results.

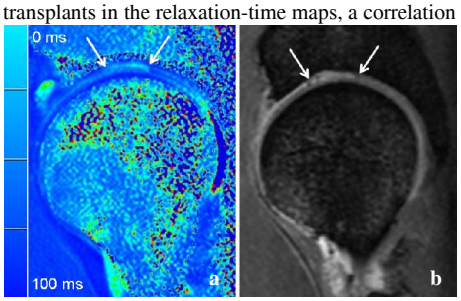

Figure 2: Sagittal 7T hip MRI of a patient with acetabular cartilage transplantation (arrows): (a) T2-map, (b) DESS.

Conclusion: A comprehensive hip cartilage protocol after intra-venous contrast agent administration is possible at 7T, including morphological sequences as well as T1-mapping for dGEMRIC, T2- and T2*-mapping.

References

1. Mosher TJ, Osteoarthritis Cartilage. 2013;21(10):1425-35
2. Burstein D, Magn Reson Med 2001;45(1):36-41
3. Welsch GH, Eur Radiol. 2010;20(6):1515-23
4. Bittersohl B, Magn Reson Med 2009;62(6):1362-7
5. Williams A, Magn Reson Med 2007;58(4):830-4
6. Welsch GH, Eur Radiol 2011;21(6):1136-43
7. Bittersohl B, Osteoarthritis Cartilage 2012;20(7):653-60
8. Chang G, MAGMA 2013;26(6):539-48

Funding: Internes Forschungsstipendium für Kliniker (IFORES, University Hospital Essen)