

Hybrid morphological and biochemical T2 evaluation of cartilage repair tissue based on a recently described double echo at steady state (DESS-T2d) approach

G. H. Welsch^{1,2}, T. C. Mamisch³, L. Zak⁴, A. Mauerer², S. Apprich¹, M. Deimling⁵, S. Marlovits⁴, and S. Trattnig¹

¹MR Center, Department of Radiology, Medical University of Vienna, Vienna, Austria, ²Department of Trauma and Orthopaedic Surgery, University Hospital of Erlangen, Erlangen, Germany, ³Department of Orthopaedic Surgery, University of Basel, Basel, Switzerland, ⁴Center for Joints and Cartilage, Department of Trauma Surgery, Medical University of Vienna, Vienna, Austria, ⁵Siemens Healthcare, Erlangen, Germany

Introduction: Morphological magnetic resonance imaging (MRI) is capable of visualizing cartilage repair tissue, the adjacent articular cartilage, and the surrounding structures, *in vivo*, at high-resolution, in clinically applicable scan times (1). A widely used morphological grading system depicting cartilage repair tissue and the adjacent structures on MRI is the Magnetic resonance Observation of Cartilage Repair Tissue (MOCART) score (2). Besides morphological MRI, biochemical MR approaches such as delayed gadolinium enhanced MRI of cartilage (dGEMRIC) or T2 relaxation time mapping are able to provide a specific measure of the composition of cartilage (3,4). In cartilage defects and following non-surgical and surgical cartilage repair, morphological MRI provides the basis for diagnosis and follow-up evaluation, whereas biochemical MRI provides deeper insight into the composition of cartilage and cartilage repair tissue. A combination of both, together with clinical evaluation, may, in the future, represent a desirable multimodal approach for diagnosis, as well as for routine clinical follow-up after cartilage repair procedures. Recently, the widely used 3D Double Echo Steady State (DESS) sequence, permitting accurate and precise analysis of cartilage morphology (5) was reported to permit the generation of biochemical T2 maps (6). Hence morphological and biochemical information of articular cartilage and cartilage repair tissue may be provided by only one hybrid sequence.

The aim of this study was to use this new DESS-T2d approach in an initial study to assess the morphological MOCART score as well as biochemical T2 values in patients after matrix-associated autologous chondrocyte transplantation (MACT) of the knee by only one sequence. Furthermore to compare the performance of this new hybrid approach to standard morphological sequences as well as standard multi-slice multi-echo spin-echo (MSME) T2 mapping.

Material and Methods: Fifty consecutive MR scans were prospectively included in this study. MRI was performed during clinical routine standard follow-up intervals post operatively after MACT of the knee joint. The 50 MR scans were performed in 43 patients with a mean age of 36.1 ± 9.3 years. MR imaging was performed on a 3 Tesla MR scanner. The MR protocol was identical for all included MR measurements. For morphological MOCART scoring it consisted of a sagittal high-resolution proton-density turbo spin-echo (PD-TSE) sequence (TR/TE 2400ms, 38 ms, flip angle 160°; 0.2x0.2x2mm; 32 slides; 6:11 min.), a sagittal T2-weighted dual fast spin-echo (dual-FSE) sequence (5120ms, 67ms; 140°; 0.4x0.4x3mm, 30 slices; 6:46 min), and a coronal T1-weighted turbo inversion recovery magnitude (TIRM) sequence (7690ms, 41ms, 150°; 0.6x0.6x3mm, 36 slices, 2:35 min.) as recommended for the evaluation of the MOCART score. Additionally the new DESS T2d sequence (6) (19.9ms, 4.2ms (S+), 35.6ms (S-), 33°; 0.4x0.4x3.0mm; 18 slides, 4:44 min) was prepared and its morphological DESS images were used for the evaluation of the MOCART score. For the evaluation of biochemical T2 relaxation times, a standard MSME sequence (TR:1200ms, TE:13.8ms,27.6ms,41.4ms,55.2ms,69ms,82.8ms,180°; 0.4x0.4x3.0mm, 12 slides, 4:09 min) was performed. Additionally the new DESS T2d sequence (6) was used to assess quantitative T2 values using a region-of-interest evaluation of the cartilage repair tissue and the surrounding control cartilage. Statistical correlation analysis was performed to (i) compare the performance of the morphological standard sequences and the morphological information of the DESS T2d sequence (Fig 1) and to (ii) compare the standard biochemical MSME T2 sequence and the biochemical DESS T2d sequence (Fig 2).

Further evaluation was prepared to classify image quality and possible artifacts for the sequences used for the morphological MOCART scoring and the quantitative T2 evaluation. For image quality, a four-level scale was used in which a score of 4 excellent-, 3 good-, 2 acceptable- and 1 poor- image quality. Artifacts were subjectively graded as absent (4), mild (3), moderate (2), and severe (1).

Results: The MOCART score for all patients was 68.8 ± 13.2 assessed with the standard morphological sequences and 68.7 ± 12.6 assessed with the morphological images of the DESS T2d sequence with a highly significant ($p < 0.001$) Pearson correlation coefficient of 0.945. When looking at the different variables of the MOCART score, the Pearson correlation coefficient for the defect fill (0.992), the cartilage (0.968), the surface (0.842), the structure (0.690), the signal intensity (0.881), the subchondral lamina (0.848), the subchondral bone (0.725), the adhesions (1.000), and the joint effusion (1.000) showed a highly significant correlation ($p < 0.001$).

T2 and T2d relaxation times are given in milliseconds (ms) for mean \pm standard deviation. Mean values for all patients were comparable within sites of control cartilage and within sites of cartilage repair; T2d values were, as expected, lower than the MSME-T2 values. Quantitative T2 values were 52.5 ± 11.4 for control cartilage and 54.4 ± 11.4 for cartilage repair tissue ($p = 0.157$) and quantitative T2d values were 46.6 ± 10.3 for control cartilage and 47.5 ± 13.0 for cartilage repair tissue ($p = 0.589$). The zonal evaluation revealed a significant increase from deep to superficial cartilage sites for the control cartilage and the repair tissue for both approaches ($p < 0.001$). The correlation in between the MSME T2 evaluation and the new DESS T2d evaluation was highly significant ($p < 0.001$) for the mean values (Pearson:0.429) as well as the deep (0.350) and the superficial (0.468) values (Figure 3). The subjective image quality was comparably good for both (standard and DESS T2d) approaches ($p = 0.361$). Visible artifacts were slightly lower for the standard approach compared to the new hybrid DESS T2d approach ($p = 0.024$).

Discussion: In conclusion, the preliminary data of this initial study demonstrates that using the DESS T2d approach, the morphological description and the biochemical T2 assessment, of the repair tissue and the surrounding control cartilage, is possible in patients after MACT using only one hybrid sequence. (i) The morphological results of the DESS T2d approach, as evaluated by the MOCART score, are comparable to the results of standard morphological MR sequences. (ii) Comparably, however with lower correlation values, the quantitative T2 values (mean T2 values as well as deep and superficial T2 values for the zonal T2 evaluation) of the DESS T2d sequence, could be correlated to the quantitative T2 values as assessed by the standard MSME-T2 sequence. Furthermore the important zonal stratification, as an increase of T2 values from deep to superficial, could be assessed using the standard T2 and the new T2d methodology with more clearly visible and more distinct stratification for healthy control cartilage compared to cartilage repair tissue. Although upcoming studies on larger patient groups and other pathologies have to proof the clinical use of the DESS T2d sequence, the presented hybrid approach provides the possibility to combine morphological and biochemical MRI in one fast 3D sequence and thus may attract for the clinical use of biochemical MRI.

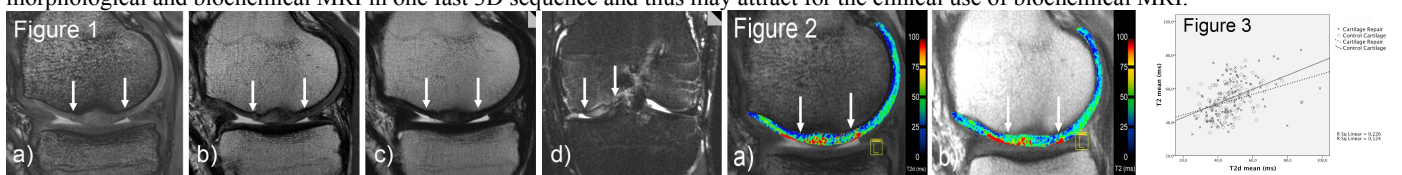


Figure 1 shows the morphological evaluation of a patient 12 months after MACT of the medial femoral condyle (arrows) with the DESS T2d (a), the PD-TSE (b), the Dual-FSE (c) and the TIRM (d) sequence. Figure 2 shows the biochemical evaluation of the same patient with the DESS T2d map (a) and a MSME-T2 map (b). Figure 3 depicts the correlation of T2 and T2d values (ms) for the control cartilage and the repair tissue, with a slightly higher correlation for the control cartilage.

References: 1. G.E. Gold et al. Orthop Clin North Am. 2006. 2. S. Marlovits et al. Eur J Radiol. 2006. 3. D. Burstein et al. Magn Reson Med. 2001. 4. T.J. Mosher et al. Semin Musculoskelet Radiol. 2004. 5. F. Eckstein et al. Annals of the Rheumatic Diseases 2006. 6. G.H. Welsch et al. Magn Reson Med. 2009.