Sodium \(^{23}\text{Na}\) MR Imaging at 7 T for the Evaluation of Repair Tissue Quality in Patients after Two Cartilage Repair Procedures

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Introduction/Purpose: Various surgical options such as bone marrow stimulation (BMS) techniques including microfracture (MFx) and Pridie drilling or matrix-associated autologous chondrocyte transplantation (MACT) are available for the treatment of articular cartilage lesions in the knee joint. One of the objectives of these procedures is the formation of repaired tissue with sufficient glycosaminoglycan (GAG) content, that provide optimal biomechanical function of the repaired tissue [1]. Since the GAG molecules are counterbalanced by sodium ions, sodium imaging can be used for the direct evaluation of GAG content in cartilage [2]. Therefore the aim of this study was to apply sodium imaging at 7T for the evaluation of repaired tissue GAG content in the patients after BMS and MACT treatment of articular cartilage.

Subjects and Methods: In total 18 patients, 9 subjects (4 women, 5 men; range: 21.4-57.7 years) who underwent one of the BMS treatments (2 Pridie drilling, 7 MFx patients) and 9 MACT patients (3 women, 6 men; range: 24.6-56.0 years) were included in this study. For better comparability, BMS and MACT patients were matched for age (BMS: 36.7±10.7 years [mean±standard deviation]; MACT: 36.9±10.0 years), postoperative interval (BMS: 33.5±25.3 months; MACT: 33.2±25.7 months) and similar defect location - medial femoral condyle (5 BMS; 5 MACT subjects), lateral femoral condyle (4 BMS; 2 MACT patients) or trochlea region (2 MACT subject). The mean defect size in MACT group was 314 mm\(^2\) (range 150-418 mm\(^2\)) and in BMS group was 184 mm\(^2\) (range 109-290 mm\(^2\)). All cartilage defects were caused by trauma or osteochondritis dissecans. Ethics approval was provided by local ethics commission and written consent was obtained from patients before measurements.

All measurements were performed on a 7T whole body system (Magnetom, Siemens Healthcare, Erlangen, Germany). For morphological evaluation of cartilage, proton-density weighted 2D-TSE sequence with fat suppression (TR/TE: 10.0/3.77 ms; FOV: 199×199 mm\(^2\); resolution: 3.11×1.55×3.0 mm\(^3\), measurement time: 30:45 min.) was performed using a sodium-only circularly polarized knee coil (Stark Contrast, Erlangen, Germany). Proton imaging took about 13 minutes and sodium imaging less than 34 minutes.

All region-of-interest (ROI) evaluations were performed with the JiveX (VISUS Technology Transfer, Bochum, Germany) software. The mean sodium signal was measured from a region covering the whole cartilage repaired tissue and a neighbouring region of normal native cartilage, at least 1 cm distant from repaired tissue. All signal-to-noise (SNR) values were calculated as mean signal intensity in the ROI divided by standard deviation of ROI from signal-free area. Magnetic resonance Observation of CArtilage Repair Tissue (MOCART) scoring system with maximum achievable (best) score of 100 points [3] was employed to evaluate morphologic condition of the repaired tissue. The analysis of variance (ANOVA), t-test and Pearson correlation coefficient (R) were used for the statistical evaluations in SPSS software (SPSS Institute, Chicago, IL). A p-value of less than 0.05 was considered statistically significant.

Results: The mean sodium SNR values in the patients after BMS techniques were 20.5±4.8 in native cartilage and 11.8±2.6 in repaired tissue (Fig.2). The patients after MACT procedure revealed the mean sodium SNR of 21.6±2.6 in native cartilage and 17.2±3.3 in repaired tissue (Fig.2). In each matched pair of patients, the ratio between sodium SNR from repaired tissue and from native cartilage was higher in MACT in comparison to BMS procedure (Fig.3). One-way ANOVA revealed significantly lower sodium SNR in repaired tissue in comparison to corresponding native cartilage in the patients after BMS procedure (p=0.001) as well as in the subjects treated with MACT (p=0.006). Although there was no significant difference in the sodium SNR from native cartilage between patients after MACT and BMS treatment (p=0.558), significantly higher sodium SNR was observed in repaired tissue after MACT procedure in comparison to BMS techniques (p=0.001) using independent sample t-test.

The mean MOCART scores were 75.0±16.6 points in BMS and 73.9±16.7 points in MACT patients. One-way ANOVA didn’t show significant difference in the morphology of repaired tissue after MACT and BMS treatment (p=0.889). No linear association between MOCART score and sodium SNR from repaired tissue was observed (R=0.013; p=0.605). There was no correlation between age and sodium SNR from native cartilage (R=-0.314; p=0.205) (Fig.4). Although no linear association between postoperative interval and sodium SNR in BMS repaired tissue was found (R=0.055; p=0.888), moderate negative correlation was achieved between postoperative interval and sodium SNR in MACT repaired tissue (R=-0.480; p=0.191).

Discussion/Conclusion: Using 3D-GRE sequence optimized for the sodium imaging of cartilage at 7T, we obtained sufficient SNR for differentiating between repaired tissue and native cartilage in the patients after BMS and MACT treatment. Significantly lower GAG content found in repaired tissue in comparison to native cartilage in both groups and the significantly lower GAG content observed in BMS repaired tissue in comparison to MACT repaired tissue correspond well with the histological findings [4,5]. In accordance with Tins et al. [4], no relationship between MOCART score and GAG content was observed. No correlation between native cartilage and patient age suggests that there is no GAG depletion in the healthy cartilage caused by the age. However, this statement must be validated in the larger cohort of healthy volunteers. We have shown that sodium imaging at 7T is feasible for the non-invasive monitoring of GAG content in repaired tissue of patients after BMS and MACT surgeries. Our results suggest that the MACT treatment provides higher GAG content and therefore higher quality repaired tissue in comparison to the BMS techniques.

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