Advanced Morphological 3D- magnetic resonance observation of cartilage repair tissue (MOCART) scoring using an isotropic PDfs-weighted 3D-TSE-sequence and an isotropic 3D-steady-state free precession sequence

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Introduction: Magnetic resonance imaging (MRI) of the knee has been reported as the method of choice to depict cartilage injuries or the post-operative constitution of cartilage repair tissue (1). A widespread array of surgical cartilage repair techniques require objective, noninvasive and reliable follow-up examination, for which the magnetic resonance observation of cartilage repair tissue (MOCART) score is claimed to be a reliable, reproducible and accurate tool for assessing cartilage repair tissue (2). This basic MOCART score comprises standard MR sequences and is performed, depending on the location of the cartilage repair site, on sagittal, axial or coronal two-dimensional (2D) planes using high spatial resolution together with a slice thickness of 2-4 mm. These sequences offer excellent image quality, but still there are some limitations in the exact detection of the repair tissue, its borders and the adjacent cartilage due to thick slices, curved curvature of cartilage layers and limited oblique reconstruction. To use the capabilities of new isovoxel sequences and their free three-dimensional (3D) multiplanar-reconstruction (MPR) without any loss of spatial resolution, the 3D-MOCART score was recently introduced based on an isotropic 3D-true fast imaging with steady-state precession (True-FISP) sequence (3). The benefits of this new 3D MOCART score and the 3D evaluation of the repair tissue could be clearly described; however a clear limitation of the 3D-True-FISP sequence in the post-operative evaluation of cartilage repair tissue was the high number of susceptibility artifacts of this gradient echo based technique within the repair tissue and the subchondral bone. A recently developed isotropic 3D-proton-density-turbo-spin-echo sequence, so called PD-SPACE (Sampling Perfection with Application optimized Contrasts using different flip angle Evolutions), might overcome these limitations with a possible lower number of artifacts and better suitability for post-operative imaging of a joint (4).

The purpose of this study was to assess the new 3D-MOCART score using (i) standard MR sequences, (ii) an isotropic 3D-TrueFISP sequence as well as (iii) an isotropic 3D-PD-SPACE sequence; furthermore to compare and to correlate the results of the 3D MOCART scoring using these 3 sequences and additionally to grade their subjective image quality and their sensitivity to artifacts.

Material and Methods: Sixty consecutive MR scans were prospectively included in this study. MRI was performed during clinical routine at standard follow-up intervals of 1, 3, 6, 12, 24, and 60 months after matrix-associated autologous condrocyte transplantation (MACT) of the knee joint, with a mean follow-up 24.3±24.1 months. The 60 MRI scans were performed on 37 patients with a mean age of 32.8 ± 7.9 years. The clinical routine MRI was performed on a 3T MR unit (Tim Trio, Siemens Healthcare, Erlangen, Germany) using a dedicated eight-channel knee coil (In vivo, Gainesville, FL, USA). The MR protocol was identical for all 60 MRIs and consisted of a set of localizers, (i) a standard MR protocol with a sagittal or axial (depending on the location of the implant) high-resolution proton-density turbo spin-echo (PD-TSE) sequence (0.2x0.2x2mm, TA: 6:11 min), a sagittal (or axial) T2-weighted dual fast spin-echo (dual-FSE) sequence (0.4x0.4x3mm, TA: 6:46 min), and a coronal T1-weighted turbo inversion recovery magnitude (TIRM) sequence (0.6x0.6x3mm; TA: 2:35 min). Furthermore (ii) an isotropic 3D-True-FISP sequence (0.4x0.4x0.4mm; TA: 6:47 min) as well as (iii) an isotropic 3D-PD-SPACE sequence (0.5x0.5x0.5mm; TA: 7:51 min).

The new 3D MOCART score with its variables 1) defect fill, 2) cartilage interface, 3) bone interface, 4) surface, 5) structure, 6) signal intensity, 7) subchondral lamina, 8) chondral osteophyte, 9) bone marrow edema, 10) subchondral bone, and 11) effusion was assessed using (i) the standard clinical sequences (with the limitation that the evaluation of the transplant could not be performed in 3D using MPR), (ii) the MPR of the isotropic-3D-True-FISP data set and (iii) the MPR of the isotropic-3D-PD-SPACE data set. The evaluation was performed on a Leonardo Workstation (Siemens, Erlangen, Germany) by a senior musculoskeletal radiologist and an orthopedic surgeon with special interest in MRI in consensus. The 3D MOCART scoring for the evaluations i), ii), and iii) of the 60 MRIs was assessed blinded to the patient and in random order.

Statistical analysis was performed to correlate the results of the 3D MOCART score assessed by the three different sequences. Further evaluation was prepared to subjectively classify image quality and possible artifacts for the sequences i), ii) and iii). For image quality, a four-level scale was used (4=excellent; 3=good; 2=acceptable and1=poor). Artifacts where graded as absent (4), mild (3), moderate (2), and severe (1).

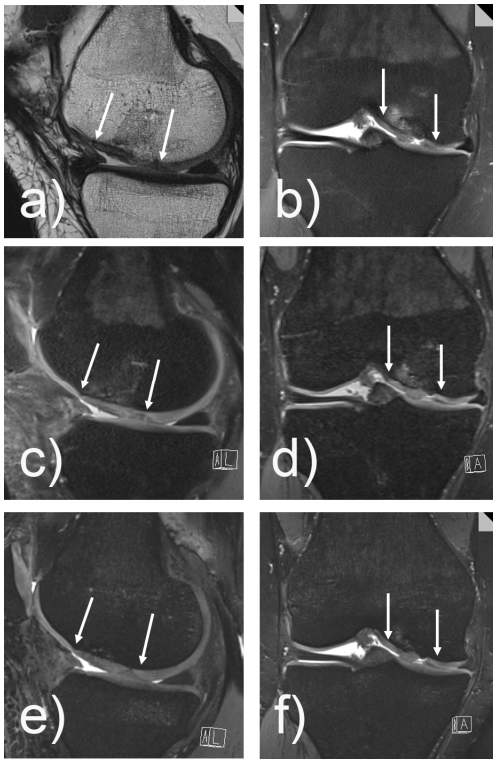

Figure 1: The cartilage repair tissue (arrows) in a patient after MACT depicted by standard MR sequences (a,b), an isotropic 3D-PD-SPACE sequence (c,d) and an isotropic 3D-True-FISP sequence (e,f). Changes within the subchondral bone are better visualized in standard MRI (a,b) and the PD-SPACE sequence (c,d).

Results: The correlation between the 3D-MOCART scoring performed by i) the standard MR sequences, ii) the 3D-True-FISP sequence and iii) the 3D-PD-SPACE sequence was highly significant for the variables 1) defect fill, 2) cartilage interface, 3) bone interface, 4) surface, 7) subchondral lamina, 8) chondral osteophyte, and 11) effusion with Pearson coefficients ranging from 0.514 to 0.865 ($p<0.001$). The variables 5) structure, 6) signal intensity, 9) bone marrow edema and 10) subchondral bone showed lower correlations especially between the i) standard MR sequences and ii) the 3D-True-FISP sequence with Pearson coefficients ranging from 0.242 to 0.383 ($p=0.061$ to 0.002). The correlations in between the i) standard sequences and iii) the 3D-PD-SPACE sequence and in between ii) the 3D-True-FISP sequence and the iii) 3D-PD-SPACE sequence revealed higher (Pearson: 0.307 to 0.633) and throughout significant ($p=0.016$ to $p<0.001$) correlations.

Concerning the subjective quality and possible artifacts, i) the standard MR sequences revealed the highest scoring (quality:4.0±0.0; artifacts:3.93±0.3) with no significant difference compared to iii) the 3D-PD-SPACE sequence (quality:3.87±0.3; artifacts:3.77±0.5) ($p\geq0.05$). For ii) the 3D-True-FISP sequence, the image quality showed comparable values (quality:3.78±0.5; $p\geq0.05$), whereas artifacts were significantly more often visible (artifacts:3.30±0.7; $p<0.05$) when comparing to i) standard sequences and the iii) 3D-PD-SPACE sequence.

Discussion: In the clinical routine follow-up after cartilage repair, the MOCART score, assessed by i) standard MR sequences, ii) the 3D-True-FISP sequence and iii) the 3D-PD-SPACE sequence, showed comparable results with significant correlations for nearly all variables, indicating that different isotropic 3D sequences can be used for the 3D evaluation of cartilage repair tissue providing comparable information than standard MR sequences with the additional benefits of isotropic 3D MRI and MPR and a significantly reduced scan time (i: 15:32min; ii: 6:47min and iii: 7:51min). Discrepancies in between the different 3D MOCART evaluations were mainly visible for the variables assessing the subchondral bone and especially the bone marrow as well as the structure and signal intensity of the repair tissue due to different sequence profiles. Although a robust evaluation was possible by both isotropic MR sequences, the 3D-PD-SPACE sequence seems to be superior due to a better performance in the subchondral bone and by the suppression of susceptibility artifacts produced by implantation and previous surgeries.

References: 1. H.G. Potter et al. Am J Sports Med. 2006. 2. Marlovits et al. Eur J Raiol 2006. 3. G.H. Welsch et al. Invest Radiol 2009. 4. C. Glaser et al. Invest Radiol. 2009.