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# Whole joint MRI assessment of surgical cartilage repair of the knee: Cartilage Repair OsteoArthritis Knee Score (CROAKS)

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SUMMARY

*Objective:* To develop a magnetic resonance imaging (MRI) scoring system for follow-up of knee cartilage repair procedures integrating assessment of the repair site and the whole joint called Cartilage Repair OsteoArthritis Knee Score (CROAKS), and to assess its reliability.
*Design:* MRI examinations of 20 patients that had undergone matrix-associated autologous chondrocyte transplantation (MACT) of the knee 12 months before were semi-quantitatively assessed for the repair site using features of the magnetic resonance observation of cartilage repair tissue (MOCART) system and for the whole joint based on experiences with the MRI Osteoarthritis Knee Score (MOAKS) instrument. Intra- and inter-observer reliability was calculated using weighted ($w$) kappa statistics for plates (medial/lateral tibia, medial/lateral femur, trochlea, patella), compartments (medial tibio-femoral, lateral tibio-femoral, patello-femoral) and the whole joint. For certain features with low prevalence the overall percent agreement was calculated in addition.
*Results:* For cartilage, reliability on a plate level ranged between 0.48 (lateral femur) and 1.00 (medial femur). BML assessment showed comparable results ranging on a plate level between 0.46 and 1.00 with overall percent agreement between 83.3% and 100%. Meniscal morphology assessment ranged between 0.62 and 0.94. For repair site assessment reliability ranged from 0.41 (signal intensity inter-observer) to 1.00 (several features). Overall percent agreement was above 80% for 17 of 22 features assessed (intra- and inter-observer results combined).
*Conclusions:* Combined scoring of the repair site and whole joint assessment for common osteoarthritis features using CROAKS, which is based on experience with two established semi-quantitative scoring tools, is feasible and may be performed with good to excellent reliability.


## Introduction

Almost 20 years have passed since the landmark publication by Brittberg *et al.* introducing surgical cartilage repair to a broad audience[1]. Since then several cartilage repair techniques have been introduced and are commonly applied now, which include matrix-associated autologous chondrocyte implantation or transplantation (MACI or MACT), microfracturing, osteochondral autologous transfer, mosaicoplasty, and osteochondral allograft techniques[2,3]. Clinical indications for cartilage repair surgery include persistent pain and limitation in function, a defined cartilage defect and ideally no associated features of osteoarthritis[4]. The ideal patient in regard to a favorable outcome seems to be a young, active and compliant person with a focal defect and no additional joint damage such as anterior cruciate ligament (ACL) tear or meniscal pathology[5]. In addition to improve pain and joint function surgical

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cartilage repair aims to preserve structure to prevent later post-traumatic osteoarthritis leading to an unfavorable outcome and ultimately total joint replacement. To assess clinical and structural outcome after cartilage repair standardized questionnaires and magnetic resonance imaging (MRI)-based assessment tools are available[4,6–9].

The latter include the magnetic resonance observation of cartilage repair tissue (MOCART) system[9], a semi-quantitative MRI-based instrument to evaluate the repair site by morphologic MRI. Furthermore, biochemical/compositional MRI techniques are able to assess cartilage ultrastructure of the repair tissue[10,11]. While the value of the MOCART score to evaluate the repair site in a longitudinal fashion including parameters such as filling of the defect, integration to the repair site borders, subchondral bone changes and others is unquestioned and the use of compositional MRI techniques to assess the matrix composition of the repair tissue is quite well established, the remaining joint has long been ignored in longitudinal studies of repair success. Hence only the repair tissue itself and the directly surrounding cartilage have been analyzed. Nevertheless it is crucial to be able to assess the whole joint after cartilage repair as the ultimate goal to prevent osteoarthritis can only be proven if the whole joint is assessed including the different tissues that are integral to the joint disease. Different whole joint MRI scoring systems for MRI assessment of osteoarthritis such as the Whole Organ Magnetic Resonance Imaging Score (WORMS), Knee Osteoarthritis Scoring System (KOSS), Boston–Leeds Osteoarthritis Knee Score (BLOKS), and recently MRI Osteoarthritis Knee Score (MOAKS) have been introduced and their reliability and validity has been proven in multiple studies[12–14]. Large ongoing osteoarthritis studies are applying these systems to achieve a better understanding of the natural history of the disease[15–19].

Integration of MRI-based whole joint assessment with the evaluation of cartilage repair procedures has merit in order to determine the long term integrity of the joint and ultimately present an outcome measure that is able to assess joint integrity or failure after such surgical approaches.

Thus, the aim of this study was to develop an integrated MRI-based semi-quantitative scoring system for the evaluation of cartilage repair and whole joint assessment in regard to knee osteoarthritis features based on two commonly applied instruments for cartilage repair and whole joint assessment that have evolved based on experiences with other systems over the last years. We will focus on the detailed description of the assessment tool, called Cartilage Repair OsteoArthritis Knee Score (CROAKS), and the presentation of reading reliability. Dimensions of this integrated scoring instrument will include repair site evaluation, e.g., cartilage and bone interface, surface, structure and signal of repair tissue and subchondral bone changes, and whole joint osteoarthritis evaluation including cartilage surface, subchondral bone marrow lesions (BMLs), meniscus, osteophytes and others.

## Methods and design

The institutional review board of the Medical University of Vienna approved the study protocol and written informed consent was obtained from all patients prior to enrollment in the study. We included 20 randomly chosen MRI examinations from a database of 61 patients who had undergone a cartilage repair procedure using MACT for one or more cartilage defects 9–12 months prior the examination. Selection of patients was blinded to clinical outcome.

MACT was performed as a two-step surgical procedure in the 20 patient knees. In a first arthroscopic step, a biopsy was taken from a non-weight-bearing area of the knee. After cell extraction and cultivation, the chondrocytes were transferred onto a biomaterial. In a second step, a mini-arthrotomy was performed to debride the cartilage defect to the subchondral bone. The cell matrix transplants were cut to size and implanted. The edges were fixed with fibrin glue[9].

### *MRI acquisition*

MRI was performed on a 3T MR system (Magnetom Tim Trio, Siemens Healthcare, Erlangen, Germany) using a dedicated eight-channel knee coil (InVivo, Gainesville, FL). All patients were positioned consistently with the joint space in the middle of the coil and the knee extended in the coil. The MR protocol was identical for all 20 MRI examinations and consisted of a set of localizers in all three planes and sequences as follows: sagittal or axial (sagittal for both femoral condyles; axial for the patella and the trochlea) high-resolution non-fat-saturated proton density turbo spin-echo (PDTSE) sequence, sagittal (or axial) PD, respectively, T2-weighted dual fast spin-echo (dual-FSE) sequence, and coronal fat-saturated proton density turbo spin-echo (FS-PD-TSE) sequence. Furthermore a coronal isotropic 3D-True-fast imaging with steady state procession (FISP) sequence was acquired. The FS-PD-TSE sequence, as well as the isotropic sequence, was performed in all patients in the same direction. The 3D-True-FISP was subsequently reconstructed in all three planes using multiplanar reconstruction (MPR). Detailed sequence parameters are provided in Table I.

### *MRI assessment and description of CROAKS*

Information of the location of the repair site was gathered from the surgical reports. The location was then translated into one or more subregions based on the articular subdivision applied in MOAKS. All subregions affected by surgical cartilage repair were assessed using the cartilage repair component of CROAKS, based on the prior experiences with the MOCART scoring system. The remaining subregions were assessed using the whole joint component of CROAKS based on prior experiences with the MOAKS instrument.

The cartilage repair assessment component was based on the validated new MOCART score including the variables defect fill, cartilage interface (in anterior–posterior as well as medial–lateral direction), bone interface, surface of the repair tissue, structure of the repair tissue, signal intensity of the repair tissue, subchondral lamina, chondral osteophyte, bone marrow edema, and subchondral bone[20]. Joint effusion was graded as based on the MOAKS part of the score. The evaluation of the cartilage repair site was performed on a Leonardo Workstation (Siemens, Erlangen, Germany) separately by a musculoskeletal radiologist (ST) with 20 years of experience in MRI assessment of cartilage repair and an orthopedic surgeon (GW) with a special interest in MRI and 10 years of experience in MRI assessment of cartilage repair. Both readers were blinded to patient name and postoperative follow-up interval and were advised only about the localization of the cartilage transplants. One of the readers (GW) re-scored all repair sites according to the cartilage repair component of CROAKS after a 4-week interval for intra-observer reliability assessment.

In addition to the assessment of the repair site the MRIs were scored separately by two musculoskeletal radiologists with 14 (AG) and 10 years (FWR) experience of semi-quantitative MRI assessment of osteoarthritis incorporating all features that are covered by the whole joint component of CROAKS excluding the subregions that included the repair site(s). In brief, cartilage and BMLs are scored in 14 articular subregions, osteophytes at eight locations and meniscal status in three subregions per meniscus. Cartilage is scored incorporating area size per subregion and percentage of subregion that is affected by full thickness cartilage loss. BMLs are assessed taking into account percentage of a subregion that is