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# Anterior Cruciate Ligament OsteoArthritis Score (ACLOAS): Longitudinal MRI-based whole joint assessment of anterior cruciate ligament injury

Frank W. Roemer †‡*, Richard Frobell §, L. Stefan Lohmander §||, Jingbo Niu ¶, Ali Guermazi ‡

† Department of Radiology, University of Erlangen-Nuremberg, Erlangen, Germany
‡ Quantitative Imaging Center (QIC), Department of Radiology, Boston University School of Medicine, Boston, MA, USA
§ Department of Orthopaedics, Clinical Sciences Lund, Lund University, Lund, Sweden
|| Institute of Sports Science and Clinical Biomechanics, University of Southern Denmark, Odense, Denmark
¶ Clinical Epidemiology and Training Unit, Department of Medicine, Boston University School of Medicine, Boston, MA, USA

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S U M M A R Y

*Objective:* To develop a whole joint scoring system, the Anterior Cruciate Ligament OsteoArthritis Score (ACLOAS), for magnetic resonance imaging (MRI)-based assessment of acute anterior cruciate ligament (ACL) injury and follow-up of structural sequelae, and to assess its reliability.

*Design:* Baseline and follow-up 1.5 T MRI examinations from 20 patients of the KANON study, a randomized controlled study comparing a surgical and non-surgical treatment strategy, were assessed for up to six longitudinal visits using a novel MRI scoring system incorporating acute structural tissue damage and longitudinal changes including osteoarthritis (OA) features. Joint features assessed were acute osteochondral injury, traumatic and degenerative bone marrow lesions (BMLs), meniscus morphology and extrusion, osteophytes, collateral and cruciate ligaments including ACL graft, Hoffa-synovitis and effusion-synovitis. Cross-sectional (baseline) and longitudinal (all time points and change) intra- and inter-observer reliability was calculated using weighted (w) kappa statistics and overall percent agreement on a compartmental basis (medial tibio-femoral, lateral tibio-femoral, patello-femoral).

*Results:* Altogether 87 time points were evaluated. Intra-observer reliability ranged between 0.52 (baseline, Hoffa-synovitis) and 1.00 (several features), percent agreement between 52% (all time points, Hoffa-synovitis) and 100% (several features). Inter-observer reliability ranged between 0.00 and 1.00, which is explained by low frequency of some of the features. Altogether, 73% of all assessed 142 parameters showed w-kappa values between 0.80 and 1.00 and 92% showed agreement above 80%.

*Conclusions:* ACLOAS allows reliable scoring of acute ACL injury and longitudinal changes. This novel scoring system incorporates features that may be relevant for structural outcome not covered by established OA scoring instruments.



## Introduction

Anterior cruciate ligament (ACL) injuries are common and serious joint injuries leading to at least 200,000 ACL reconstructions performed each year in the United States with estimated direct costs of $3 billion annually despite a lack evidence for superiority in comparison to non-operative treatment[1]. The purpose of ACL reconstruction is to improve stability of a mechanically unstable knee and to reduce the risk of subsequent meniscal or chondral damage and ultimately osteoarthritis (OA)[2,3]. However, long-term radiographic studies suggest that ACL reconstruction may not protect against the development of post-traumatic OA[4,5] with reported rates of OA varying between 10% and 90% at 10–20 years after the ACL injury[2,4–8].

In the KANON study, a randomized controlled trial comparing a surgical and non-surgical treatment strategy, a prevalence of

* Address correspondence and reprint requests to: F.W. Roemer, Department of Radiology, University of Erlangen-Nuremberg, Maximiliansplatz 1, 91054 Erlangen, Germany. Tel: 49-9131-8536065; Fax: 49-9131-8536068.

*E-mail addresses:* frank.roemer@uk-erlangen.de, froemer@bu.edu, frank.roemer@klinikum-augsburg.de (F.W. Roemer).

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radiographic tibio-femoral or patello-femoral OA was reported to be 12% and 19%, respectively, at 5 years post trauma, with no differences in regard to treatment arm[9]. However, radiography is only able to depict osteoarthritic joint changes late in the disease course once overt osseous adaptations are detectable[10]. Pre-radiographic tissue alterations may be visualized by magnetic resonance imaging (MRI) with a recent study reporting such changes in more than 90% of knees without radiographic OA in a population based study[11]. A recent systematic review and meta-analysis showed that macroscopic cartilage alterations are detectable as early as 2 years post trauma preceded by ultra-structural and functional changes in the lateral and medial compartment[12]. Others have reported concomitant cartilage damage for all ACL injured knees already at the time of injury[13]. Meniscal lesions and meniscectomy, presence of bone marrow lesions (BMLs), and persisting altered biomechanics, possibly further influence cartilage change following ACL disruption regardless of treatment[12].

Several semiquantitative MRI-based scoring systems for the cross-sectional and longitudinal evaluation of knee OA are available[14–17]. However, these instruments are only partially applicable for the assessment of ACL injury as they do not include a detailed description of the baseline injury pattern, which may predict outcome[18]. Further, subchondral bone changes due to trauma need to be differentiated from degenerative BMLs, which are also not covered by commonly used OA scoring tools. Finally, graft assessment and indirect MRI signs of instability such as anterior tibial shift and increased posterior cruciate ligament (PCL) bowing need to be incorporated[19–21]. Given the individual and socio-economic burden of ACL injury and subsequent development of OA, there is a need for reliable instruments to describe the baseline injury and monitor the development of post-traumatic structural joint alterations[1,12]. As there is a need for individualized treatment strategies of ACL injuries, there is also need for a tool that is able to cover structural changes in a non-invasive fashion in surgically and non-surgically treated joints in order to evaluate efficacy of such individualized treatment[10]. MRI is widely available in both the clinical and research environment. Due to its capabilities of visualizing all relevant joint components, longitudinal MRI assessment will enable a better understanding of the natural history of post-traumatic structural damage, define risk factors for unfavorable outcome, and assess the structural outcome of treatment[10,22].

The aim of the present study was to describe an MRI-based instrument, the Anterior Cruciate Ligament OsteoArthritis Score (ACLOAS), that incorporates acute traumatic and subsequent degenerative alterations, and to test its reliability.

## Methods and design

### *KANON study and subject inclusion*

The KANON study is a randomized controlled trial (ISRCTN 84752559) comparing a surgical and non-surgical treatment strategy of acute ACL injuries including 121 subjects with an acute ACL injury in a previously un-injured knee[9,23]. Subjects were randomly assigned to structured rehabilitation plus early ACL reconstruction (i.e., surgical treatment arm) or to structured rehabilitation plus optional delayed ACL reconstruction (i.e., non-surgical treatment arm). A subset of 63 subjects were followed intensely with MRI over the first year after injury (baseline, 3 months, 6 months and 1 year after injury), and were assessed at year 2 and year 5 in addition. 62 participants had MR images available at the baseline, the year 2- and year 5-visit only. For several reasons, not all participants were able to attend all MRI visits leaving in total 120 subjects with any MRI visit. Of these, eight had two visits, 46 had three visits, two had four visits, four had five visits and 57 had six visits available for assessment. For 119 subjects, the baseline visit was available. The study was approved by the ethics committee of Lund University (LU 535-01).

### *MRI acquisition*

MRI was performed using a 1.5 T system (Gyroscan, Intera, Philips, Best, Netherlands) with a circular polarized surface coil using identical sequences for all subjects and all time points. The MRI pulse sequence protocol consisted of a sagittal 3D water excitation Fast Low Angle Shot (FLASH) sequence with repetition time (TR)/echo time (TE)/flip angle of 20 ms/7.9 ms/25° and a sagittal T2*-weighted 3D gradient echo (GRE) sequence with TR/TE/flip angle of 20 ms/15 ms/50°. Both series were acquired with a 15 cm × 15 cm field of view (FOV), 1.5 mm slice thickness, and 0.29 mm × 0.29 mm pixel size. In addition, a sagittal and coronal dual echo turbo spin echo (DETSE) sequence, with a TR/TE of 2900 ms/15 ms and 80 ms, 15 cm × 15 cm FOV, 3 mm slice thickness, 0.6 mm gap and 0.59 mm × 0.59 mm pixel size, and sagittal and coronal Short Tau Inversion Recovery (STIR) sequences with a TR/TE/TI of 2900 ms/15 ms/160 ms, 15 cm × 15 cm FOV, 3 mm slice thickness, 0.6 mm gap and 0.29 mm × 0.29 mm pixel size were acquired. Quality control of the MRI scanner was performed at each scan using volumetric phantoms attached to the knee using a standardized and calibrated uniformity and linearity phantom.

### *MRI assessment*

Of the 120 participants, 20 patient IDs were randomly selected for reliability assessment with 10 randomly chosen from the surgical treatment arm and 10 from the non-surgical treatment arm. Of these 20 patients, two had two visits (baseline and year 2), nine had three visits (baseline, year 2 and year 5), one had five visits (first five visits but not the 5 year visit) and seven had all six visits available. In total, 87 visits were used for the reliability exercise.

All available MRIs were read primarily by one musculoskeletal radiologist (FWR) with 11 years experience in standardized semiquantitative MRI assessment of knee OA. The intra-observer reliability exercise was performed 2 months after the initial scoring with MRIs being presented to the reader in random order. A second radiologist (AG) with 13 years experience of semiquantitative OA assessment read these same 20 cases in random order for the inter-observer reliability assessment. All visits were read for all participants. The readers were blinded to patient's name and date of birth. Blinding to treatment was not possible as the readers were able to see post-surgical changes such as susceptibility artifacts and ACL graft. Readings were commenced after two separate 2-h training sessions of calibration between the readers using 20 different cases from the KANON trial. All features were assessed in at least two perpendicular imaging planes. All readings were done with the chronological order of visits unblinded to the readers in order to maximize sensitivity to detect change[24].

Readings were performed using the cine-loop function on a standard clinical PACS system (GE Healthcare, Centricity™, Barrington, IL). Scores were recorded electronically on a designated custom-developed score sheet (MS Access, Microsoft™, Redmond, WA).

Images were scored with respect to articular features that are relevant to a.) baseline injury pattern and longitudinal follow-up of those features and b.) incident degenerative features reflecting structural damage associated with OA. Features assessed were osteochondral surface damage at baseline including subchondral BMLs (i.e., bone contusions), cartilage morphology, longitudinal assessment of subchondral traumatic BMLs for visits one through six, degenerative BMLs, native ACL and PCL, ACL graft, collateral ligaments (only at baseline and visit six), femoral and tibial tunnels,