MR Imaging-based Semi-quantitative Methods for Knee Osteoarthritis

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Magnetic resonance imaging (MRI)-based semi-quantitative (SQ) methods applied to knee osteoarthritis (OA) have been introduced during the last decade and have fundamentally changed our understanding of knee OA pathology since then. Several epidemiological studies and clinical trials have used MRI-based SQ methods to evaluate different outcome measures. Interest in MRI-based SQ scoring system has led to continuous update and refinement. This article reviews the different SQ approaches for MRI-based whole organ assessment of knee OA and also discuss practical aspects of whole joint assessment.

Keywords: magnetic resonance imaging, knee, osteoarthritis, semi-quantitative scoring

Introduction

Over the last two decades magnetic resonance imaging (MRI) has increasingly established itself as the most important imaging modality in assessing joint pathology in the clinical and research environment. Initially, cartilage was in the focus of clinical and epidemiological studies applying MRI for the assessment of knee osteoarthritis (OA), and semi-quantitative (SQ) scoring methods were introduced for that purpose for both cross-sectional and longitudinal evaluations. However, the potential of MRI for the assessment of other joint structures was soon recognized. Validated tools for whole-organ assessment of the OA joint were subsequently introduced to better reflect the complexity of interaction of different joint components in knee OA. These tools have since been applied to several OA studies, which greatly added to the understanding of the pathophysiology and natural history of knee OA as well as the clinical and prognostic implications of structural changes assessed.

MRI-based SQ assessment is based on multi-feature grading of the knee joint using conventional acquisition techniques that are applied in a clinical environment. Scores are visually (semi-quantitatively) assigned by expert readers to a variety of features believed to be relevant to the functional integrity of the knee, or potentially involved in the pathophysiology of OA, or both. These features include cartilage damage, subarticular bone marrow lesions (BMLs) (or bone marrow edema-pattern), subchondral cysts, subarticular bone attrition, marginal and central osteophytes, medial and lateral meniscal tears and extrusions, anterior and posterior cruciate ligaments damage, medial and lateral collateral ligament damage, synovitis and effusion, and intra-articular loose bodies, as well as periarticular cysts and bursitis.

The first comprehensive MRI-based SQ scoring system was published in 2004, and named Whole Organ Magnetic Resonance Score (WORMS). WORMS has been extensively used in OA studies worldwide. Since then three more additional scoring systems have been introduced; the Knee Osteoarthritis Scoring System (KOS), the Boston Leeds Osteoarthritis Score (BLOKS), and the MRI Osteoarthritis Knee Score (MOAKS). In this article, we aim to review the different SQ approaches for MRI-based whole organ assessment of knee OA and also discuss practical aspects of whole joint assessment.

Technical Considerations

Since OA affects several joint structures, and is believed to progress through multiple pathogenic pathways, the MRI sequence protocol has to support...
multi-feature structural assessment of the knee. An optimal protocol includes the minimum number of sequences possible without compromising the integrity of whole-organ assessment of most articular features. Intermediate weighted “fluid-sensitive” fat-suppressed fast spin echo (FSE) sequences (applying a frequency-selective saturation pulse) are particularly important and should be acquired in three different orthogonal planes (axial, sagittal, and coronal) for accurate localization and volume estimation of BMLs in different joint compartments. As an alternative, short tau inversion recovery (STIR) sequences or similar inversion recovery sequences may be applied, as these are very robust especially concerning susceptibility artifacts. Other methods of fat suppression such as water excitation (e.g., fast low angle shot, FLASH) are less suited as these depict BMLs inferiorly and are prone to susceptibility artifacts. Standard FSE fat suppressed sequences are also optimal for assessment of focal cartilage defects. Gradient-echo sequences, such as dual-echo steady state (DESS), fast low-angle shot (FLASH), and spoiled gradient-recalled (SPGR), have been shown to be insensitive for BML detection but are well suited for cartilage evaluation, especially for quantitative analysis such as measurement of volume and thickness. Gradient-echo sequences are particularly prone for susceptibility artifacts, which are likely to represent vacuum phenomenon within the OA joints. Sagittal or coronal three-dimensional (3D) high-resolution GRE sequences help in the optimal evaluation of articular cartilage and osteophytes, and offer the possibility of three-plane reconstruction. A sagittal or coronal T1-weighted spin echo sequence may be added for better visualization of osteophytes, loose bodies, and sclerosis.

Designing an optimal pulse sequence protocol depends on the structures/features that will be included in the assessment and the measurement methods applied, e.g., SQ and/or quantitative analyses, as well as the convenience and cost. Recommendations for choosing appropriate MRI protocols for assessment of OA features have been published. Suggested pulse sequences for optimum SQ evaluation of knee OA include “fluid-sensitive” FSE sequences (2D) in three orthogonal planes. Axial images are optimal for the study of effusion/synovitis, popliteal cysts, and different OA features of the femoropatellar and posterior femoral compartments. Sagittal and coronal images are helpful in assessing the central femoro-tibial compartment, as well as the menisci. The study of ligaments requires the use of all three orthogonal planes. 3D high-resolution MR sequences can be obtained in any plane and reformatted in two other orthogonal views. These volumetric images contribute to optimal evaluation of cartilage and osteophytes. Sagittal/coronal T1-weighted images are helpful for osteophyte and meniscus evaluation. Recently, 3D FSE fat suppressed sequences have been introduced that allow triplanar reformation with acquisition of a single sequence to achieve similar imaging characteristics as with three orthogonal 2D sequences. Drawback is blurring, which has hindered wide spread application in OA research. One study showed comparable results for 2D vs. 3D FSE sequences for SQ OA assessment.  

**SQ Assessment of Knee Joint in Osteoarthritis**

*Whole joint assessment on knee MRI*

MRI-based whole organ scoring of different joint structures has shown adequate reliability, specificity, sensitivity, and responsiveness. Since the publication of the MRI-based comprehensive SQ scoring system by Peterfy et al. in 2004, named WORMS, three additional whole-organ systems for the knee have been introduced: KOSS, BLOKS, and MOAKS.

All the SQ scoring systems described in this review are publicly available; however images should be read by trained readers for accurate and reliable grading.

In 2011, a study comparing SQ and quantitative approaches for the assessment of cartilage damage and BML showed that quantitative analyses are more sensitive to change during a 24-month observation period than SQ scoring. The relative lack of sensitivity to change is a potential weakness of semi-quantitative approaches when compared to quantitative methods. Therefore, scoring “within-grade” changes between time points have been introduced to increase longitudinal sensitivity. These within-grade changes designate a definite change from the previous visit that does not fulfill the criteria of a full grade change as defined by the scoring system. Also, clinical relevance of within-grade changes has been established as they were shown to be associated with known OA risk factors and outcomes. Scoring within-grade change is particularly useful in clinical trials, since full-grade changes may not occur within a relatively short follow-up of <1 year in a typical clinical trial of OA.

When deciding which scoring system should be applied for the assessment of a given study, different aspects have to be considered such as the outcome measures that are relevant to the study, the resources, and the available image data set.  

**Whole Organ Magnetic Resonance Imaging Score (WORMS)**

Peterfy et al. published WORMS in 2004. Many epidemiologic studies and clinical trials have used WORMS to semi quantitatively assess several OA features of the knee. To date, WORMS is the most widely cited...
MRI-based SQ scoring system for knee OA with 197 citations in a “PUBMED” search as of May 2015. In the WORMS protocol, a complex system for division of the knee is used, based on a subregional rather than lesion-oriented approach to scoring, especially for cartilage (Fig. 1), BMLs, and cysts. The advantage of the subregional approach is that for each subregion multiple lesions are evaluated together, which facilitates interpretation and subsequent analysis of data (Figs. 2, 3). Defining the exact number of lesions can be difficult...
since these can merge or split over the course of longitudinal studies. Furthermore, WORMS is the only SQ scoring system that assesses subchondral bone attrition, defined as flattening or depression of the articular surface unrelated to trauma.

KOSS

Kornaat et al. introduced KOSS in 2005. Although it covers similar OA features to those analyzed using WORMS (Table 1), cartilage status, BMLs, and cysts are scored individually for each subregion in KOSS (rather than additively in WORMS). The different BML grades are differentiated by the size of the lesion. Synovitis is scored present or absent on T₁-weighted gradient-recalled echo images. Scoring of meniscal tear is more complex than WORMS, but does not take into account the regional subdivision, nor does it score partial or complete maceration. Meniscal subluxation is scored in addition to meniscal morphology. Furthermore KOSS uses a different subregional division than WORMS.

BLOKS

The BLOKS scoring system was introduced by Hunter et al. in 2008. BLOKS divides the knee joint into weight bearing vs. patello-femoral compartments, similar to KOSS. The patellar surface is divided into lateral and medial facets, as in WORMS. BMLs and cysts are scored in a complex manner taking into account the size of the BML, percentage of involved subchondral surface area of the BML, and percentage of the BML that is cyst. Therefore, cysts are scored as cystic portion of BML, not separately as in WORMS and KOSS. The lesional approach used in BLOKS to score BMLs, allows superior longitudinal analyses of individual lesions especially with regard to change in cystic/non-cystic components. Indeed, a comparison of BML scoring according to associations with pain and cartilage loss performed during the original BLOKS study found that BLOKS performed better than WORMS for assessment of these lesions. On the other hand, the definition of each lesion is time-consuming and differentiation among individual lesions can be uncertain because of the ill-delineated nature of the lesions.

BLOKS assigns a score for the amount of BML that is adjacent to the subchondral plate allowing for differentiation of depth of BMLs with regard to the subchondral plate. Two scores are reported for cartilage. The first refers to the percentage of any cartilage loss in the subregion and the percentage of full-thickness cartilage damage for the same subregion. The second score describes the cartilage status on specific landmark-defined image sections and differentiates partial and full thickness cartilage loss.

MOAKS

There are limited studies directly comparing KOSS, WORMS, and BLOKS in the literature. In 2011, two
|                          | WORMS                                    | KOSS                                     | BLOKS                                    | MOAKS                                    |
|--------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| **Subregional division of knee** | 15 subregions: medial/lateral patella, medial/lateral femur (anterior, central, posterior), medial/lateral tibia (anterior, central, posterior), subspinous tibia | 9 subregions: medial patella, patellar crest, lateral patella, medial/lateral trochlea, medial/lateral femoral condyle, medial/lateral tibial plateau | 9 subregions: medial/lateral patella, medial/lateral trochlea, medial/lateral weight-bearing femur, medial/lateral weight-bearing tibia, subspinous tibia | 15 subregions: medial/lateral patella, medial/lateral femur (anterior, central, posterior), medial/lateral tibia (anterior, central, posterior), subspinous tibia for BML only |
| **Scored MR imaging features** |                                           |                                          |                                         |                                          |
| **Cartilage**            | Subregional approach: scored from 0 to 6 depending on the depth and extent of cartilage loss. Intrachondral cartilage signal additionally scored as present or absent | Subregional approach: focal and diffuse defects are differentiated. Depth of lesions is scored from 0 to 3. Diameter of lesion is scored from 0 to 3. Osteochondral defects are scored separately | Two different scores | Compared to BLOKS: |
|                          |                                           |                                          | • Score 1: subregional approach | • Score 1: same |
|                          |                                           |                                          | A. Percentage of any cartilage loss in subregion |                                           |
|                          |                                           |                                          | B. Percentage of full-thickness cartilage loss in subregion |                                           |
|                          |                                           |                                          | • Score 2: site-specific approach. Scoring of cartilage thickness at 11 specific locations (not subregions) from 0 [none to 2 (full thickness loss)] | • Score 2: omitted |
| **Bone marrow lesions**  | Summed BML size/volume for subregion from 0 to 3 in regard to percentage of subregional bone volume | Individual lesions from 0 to 3 concerning maximum diameter of lesion | Individual lesions. Three aspects are scored: | Summed BML for subregion Three aspects scored: |
|                          |                                           |                                          | • Size: form 0 to 3, concerning percentage of subregional bone volume (thresholds, 10–85%). | • Size: from 0 to 3, concerning percentage of subregional bone volume (thresholds, 33–66%) |
|                          |                                           |                                          | • Percentage of surface area adjacent to subchondral plate. | • Percentage of surface area adjacent to subchondral bone omitted |
|                          |                                           |                                          | • Percentage of BML that is noncystic | • Percentage of BML that is noncystic unchanged |
| **Subchondral cysts**    | Summed cyst size/volume for subregion from 0 to 3 in regard to percentage of subregional bone volume | Scoring of individual lesions from 0 to 3 concerning maximum diameter of lesion | Scored together with BMLs | Scored together with BMLs |
| **Osteophytes**          | Scored at 16 sites from 0 to 7 | Scored from 0 to 3 Marginal intercondylar and central osteophytes are differentiated Locations/sites of osteophyte scoring not forwarded | Scored at 12 sites from 0 to 3 | Unchanged |
| **Bone attrition**       | Scored in 14 subregions from 0 to 3 | Not scored | Not scored | Not scored |

Continued
|                              | WORMS                          | KOSS                           | BLOKS                                                                 | MOAKS                                                                 |
|------------------------------|--------------------------------|--------------------------------|-----------------------------------------------------------------------|-----------------------------------------------------------------------|
| Effusion                     | Scored from 0 to 3              | Scored from 0 to 3              | Scored from 0 to 3                                                    | Scored from 0 to 3                                                    |
| Synovitis                    | Combined effusion/synovitis    | Synovial thickening described as present or absent on sagittal $T_1$ W SPGR sequence (location not described) | A. Scoring of size of signal change in Hoffa’s fat pad                | Score of 0 to 3 applied to signal changes in Hoffa’s fat pad. Feature renamed as “Hoffa-synovitis” |
|                              |                                |                                | B. Five additional sites scored as present or absent (details of scoring not described) |                                                                      |
| Meniscal status              | Anterior horn, body, posterior horn scored separately in medial/lateral meniscus from 0 to 4: 1: Minor radial or parrot beak tear 2: Nondisplaced tear or prior surgical tear 3: Displaced tear or partial resection 4: Complete maceration or destruction or complete resection | No subregional division of meniscus described. Presence or absence of following tears: • Horizontal tear • Vertical tear • Radial tear • Complex tear • Bucket-handle tear • Meniscal intrasubstance degeneration scored from 0 to 3 | Anterior horn, body, posterior horn scored separately in medial/lateral meniscus. Presence absence scored: • Intrameniscal signal • Vertical tear • Horizontal tear • Complex tear • Root tear • Macerated • Meniscal cyst | Similar to BLOKS but added: • Hypertrophy • Partial maceration • Progressive partial maceration |
| Meniscal extrusion           | Not scored                      | Scored on coronal image from 0 to 3 | Scored as medial and lateral extrusion on anterior extrusion for medial and lateral meniscus on sagittal image form 0 to 3 | Unchanged                                                               |
| Ligaments                    | Cruci ates ligaments and collateral ligaments scored as intact or torn | Not scored                      | Cruci ates ligaments scored as normal or complete tear                | Unchanged                                                               |
|                              |                                |                                | Associated inser tional BMLs are scored in tibia and in femur         |                                                                      |
|                              |                                |                                | Collateral ligaments not scored                                       |                                                                      |
| Peri-articular features      | Popliteal cysts, anserine bursitis, semimembranosus bursa, meniscal cyst, infrapatellar bursitis, tibiofibular cyst scored 0 to 3. | Only popliteal cysts scored from 0 to 3                                | The following features are scored as present or absent: • Patella tendon signal • Pes anserine bursitis • Iliotibial band signal • Popliteal cyst • Infrapatellar bursa • Ganglion cysts of the TFJ, meniscus, ACL, PCL, semimembranosus, semitendinosus, other | Unchanged                                                               |
| Loose bodies                 | Scored from 0 to 3 depending on number of loose bodies | Not scored                      | Scored as absent or present                                          | Unchanged                                                               |

ACL, anterior cruciate ligament; BLOKS, Boston Leeds Osteoarthritis Knee Score; BML, bone marrow lesion; KOSS, Knee Osteoarthritis Scoring System; MR, magnetic resonance; PCL, posterior cruciate ligament; TFJ, tibio-fibular joint; WORMS, Whole-Organ Magnetic Resonance Imaging Score.
studies compared WORMS and BLOKS on a limited sample of 115 knees with radiographic OA from the osteoarthritis initiative (OAI). Although both systems had high reliability, Felson et al. recommended that both methods should be combined as BLOKS performed better for menisci, while WORMS was superior for analysis of BMLs. For example, WORMS meniscal scoring mixes multiple different constructs, while BLOKS clearly differentiates different tear types from intrameniscal signal changes and substance loss, i.e. meniscal maceration. BML scoring in BLOKS is complex due to the different dimensions and particularly due to the lesional approach that makes application in longitudinal studies challenging as lesions may merge and split over time. Limitations of both methods urged investigators to develop a new scoring instrument that integrated the advantages of both WORMS and BLOKS but minimizing the drawbacks of both systems.

The same year a new scoring system was developed and introduced, mainly based on experts’ experience of existing scoring tools and the available comparative data, termed MOAKS. MOAKS refined scoring of BMLs and elements of meniscal morphology (Fig. 4), added subregional assessment, and omitted some redundancy in BML and cartilage scoring. Regarding osteophyte scoring, MOAKS uses a four-scale grading system as in BLOKS (Fig. 5). Scoring of effusion remained same as the previous systems (Fig. 6).

While MOAKS is the newest of the four systems described in this review and requires further validation, it has been used in large-scale studies including the multicenter randomized controlled MeTeOR (Meniscal Tear with Osteoarthritis Research) trial, which examined whether arthroscopic partial meniscectomy resulted in better functional outcomes than non-operative therapy, and the OAI. A recent publication using data from the latter study demonstrated that severity of structural damage can be used as predictor of knee replacement a year later and also predicts the radiographic onset of OA.

**Synovitis-specific SQ Scoring Systems**

All whole joint scoring systems have in common the non-inclusion of contrast-enhanced images. However, signal changes detected in Hoffa’s fat pad on “fluid-sensitive” sequences only have been shown to be non specific, although sensitive, finding for synovitis. It has been shown that only contrast-enhanced (CE) MRI-detected synovitis correlates with histological findings. Therefore, CE-MRI is the only method that accurately assesses the true extent of synovitis in knee OA. Three different scoring systems to assess synovitis on the basis of CE-MRI have been published. The grading system developed by Guermazi et al. is a three-scale scoring system assessing 11 sites, and has high intra- and inter-reader agreement. In a recent publication it has been shown that CE-MRI-detected synovitis strongly correlates with tibiofemoral radiographic OA and MR-detected widespread cartilage damage.

**Conclusion**

SQ assessment of knee OA on MRI is a valid, reliable, and responsive tool for the understanding of the natural history of OA and the evaluation of therapeutic effects.
Fig. 5. Osteophytes are one of the hallmark features of OA on imaging and part of the disease definition on X-rays. While WORMS uses a complex approach of osteophytes scoring on a 0–7 scale at 16 articular anatomical locations, MOAKS applies a somewhat simplified scheme on a 0–3 scale at only 12 different locations omitting the scores of the anterior and posterior medial and lateral tibia. (A) Sagittal fat-suppressed intermediate-weighted image of the lateral tibio-femoral compartment shows a moderate sized MOAKS grade 2/WORMS grade 4 osteophyte at the anterior femur, a MOAKS grade 3/WORMS grade 5 osteophyte at the posterior femur (short white-filled arrows), and a WORMS grade 5 osteophyte (long black-filled arrow) at the anterior lateral tibia (location not considered in MOAKS). (B) Marginal osteophytes in the coronal plane are similarly considered in MOAKS and WORMS. Example shows femoral osteophytes (small arrows; MOAKS grade 2/WORMS grade 4 medial; MOAKS grade 3/WORMS grade 6 lateral) and a moderate osteophyte at the medial tibia (large arrow; MOAKS grade 2/WORMS grade 4). There is diffuse cartilage loss at the central lateral tibial and femur with moderate lateral tibial plateau remodeling (attrition). (C) Sagittal dual-echo at steady-state (DESS) MRI of the medial tibio-femoral compartment shows moderate-sized (MOAKS grade 2/WORMS grade 3) osteophytes at the anterior and posterior medial femur (small white-filled arrows). At the tibia (large white-filled arrows) there is a tiny anterior osteophyte (WORMS grade 1) and a moderate-to-large sized posterior osteophyte (WORMS grade 5). Tibial locations are not scored in the sagittal plane using MOAKS. MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; OA: osteoarthritis; WORMS, Whole Organ Magnetic Resonance Score.

Fig. 6. MRI of markers of inflammation in OA. Fluid sensitive sequences are capable of delineating intraarticular joint fluid. However, a distinction between true joint effusion and synovial thickening is not possible as both are visualized as hyperintense signal within the joint cavity. For this reason the term effusion-synovitis has been introduced, which is scored based on the distention of the joint capsule for both systems, WORMS and MOAKS, and is graded collectively from 0 to 3 in terms of the estimated maximal distention of the synovial cavity with 0 = normal, grade 1 = <33% of maximum potential distention, grade 2 = 33–66% of maximum potential distention, and grade 3 = >66% of maximum potential distention. Axial dual-echo at steady-state (DESS) MR images show (A) grade 1 effusion-synovitis, (B) grade 2 effusion-synovitis (asterisk), and (C) grade 3 effusion-synovitis (asterisk). MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; OA: osteoarthritis; WORMS, Whole Organ Magnetic Resonance Score.
possibilities. SQ scoring systems have been applied in large-scale, multi-center epidemiological studies, as well as interventional clinical trials. Considering the ongoing effort for deeper understanding of OA and the development of disease-modifying drugs for knee OA, iterative refinement of SQ scoring systems will also continue.

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