Magn Reson Med Sci, Vol. 15, No. 2, pp. 153–164, 2016
doi:10.2463/mrms.rev.2015-0058

REVIEW

MR Imaging-based Semi-quantitative Methods for Knee Osteoarthritis

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(Received May 29, 2015; Accepted October 9, 2015; published online December 1, 2015)

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.[1] Initially, cartilage was in the focus of clinical and epidemiological studies applying MRI for the assessment of knee osteoarthritis (OA),[2–4] and semi-quantitative (SQ) scoring methods were introduced for that purpose for both cross-sectional and longitudinal evaluations.[5–7] However, the potential of MRI for the assessment of other joint structures was soon recognized.[8–11] 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.[6,12,13] 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.[14–25]

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).[6] WORMS has been extensively used in OA studies worldwide. Since then three more additional scoring systems have been introduced; the Knee Osteoarthritis Scoring System (KOSS), the Boston Leeds Osteoarthritis Score (BLOKS), and the MRI Osteoarthritis Knee Score (MOAKS).[12,13,26]

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

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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.[27] 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.[28] 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.[29] Standard FSE fat suppressed sequences are also optimal for assessment of focal cartilage defects.[30] On the other hand, 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,[27,31] but are well suited for cartilage evaluation, especially for quantitative analysis such as measurement of volume and thickness.[32] Gradient-echo sequences are particularly prone for susceptibility artifacts, which are likely to represent vacuum phenomenon within the OA joints.[33] 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 T_1-weighted spin echo sequence may be added for better visualization of osteophytes, loose bodies, and sclerosis.[27]

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.[34] 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 T_1-weighted images are helpful for osteophyte and meniscus evaluation.[27,35] 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.[36]

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.[6,12,13,17,37] Since the publication of the MRI-based comprehensive SQ scoring system by Peterfy et al. in 2004,[6] named WORMS, three additional whole-organ systems for the knee have been introduced: KOSS,[13] BLOKS.[12] and MOAKS.[26]

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.[38] 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.[39] 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.[39] 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[40] 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.[1]

Whole Organ Magnetic Resonance Imaging Score (WORMS)

Peterfy et al. published WORMS in 2004.[6] Many epidemiologic studies and clinical trials have used WORMS to semi quantitatively assess several OA features of the knee.[14,41,42] To date, WORMS is the most widely cited

Fig. 1. Typical image examples for different types of cartilage damage. (**A**) A focal superficial defect (arrow) not reaching the subchondral plate is shown in this coronal intermediate-weighted MRI (arrow). Lesion will be coded as a grade 1.0 lesion in MOAKS or as grade 2 in WORMS. (**B**) Coronal intermediate-weighted MRI shows a focal defect (arrow) that reaches the subchondral plate and is consequently defined as a grade 1.1 lesion using MOAKS. In WORMS this lesion would be scored as a 2.5 lesion. A 2.5 lesion is not a reflection of a within-grade coding but a distinct grade by itself. (**C**) Sagittal intermediate-weighted fat-suppressed MRI depicts diffuse full thickness cartilage damage in the central subregion of the medial femur and the central medial tibia (large arrows) representing grade 2.2. lesions in MOAKS, and grade 5 lesions in WORMS. There are associated subchondral bone marrow lesions (small arrows). MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; WORMS, Whole Organ Magnetic Resonance Score.

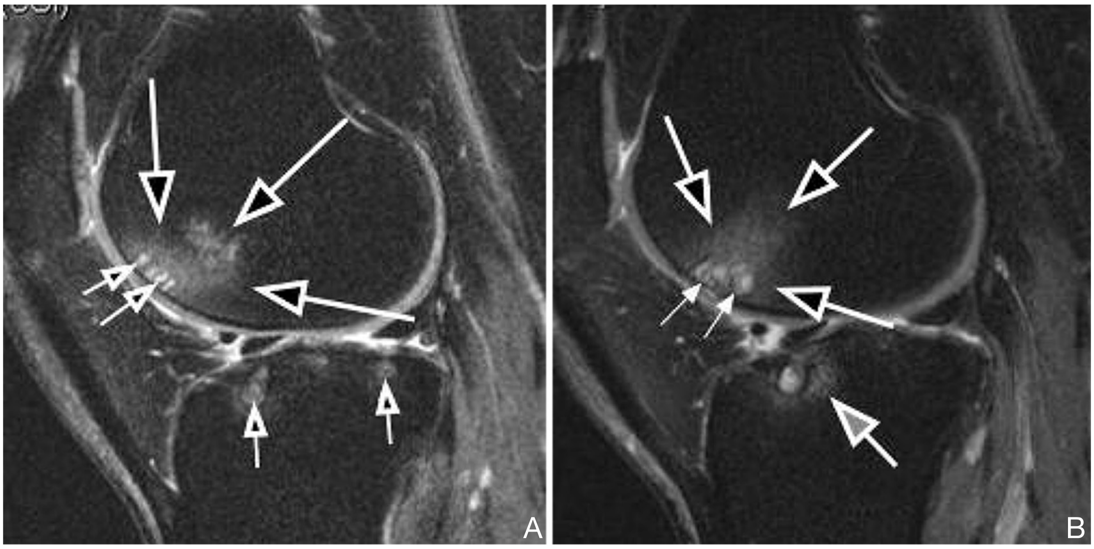

Fig. 2. Example of longitudinal assessment of bone marrow lesions (BMLs) in the lateral tibio-femoral compartment. (**A**) Baseline sagittal intermediate-weighted fat-suppressed MRI shows a grade 2 MOAKS/grade 3 WORMS BML in the anterior lateral femur displaying high signal intensity, comprised of an ill-defined (edema-like) component (large arrows) and a well-defined cystic component (small arrows). In addition, there are small cystic BMLs in the subchondral anterior and posterior lateral tibia (small arrows). (**B**) Follow-up MRI 1 year later shows slight decrease of overall lesion size (within-grade change for MOAKS, and change from grade 3 to grade 2 for WORMS) in the femur (large arrows, black-filled) but increase of size of femoral cystic component (small arrows). Note regression of cystic lesion in the posterior lateral tibia and increase of ill-defined (edema-like) portion of BML in the anterior lateral tibia (large arrow, gray-filled). MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; WORMS, Whole Organ Magnetic Resonance Score.

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

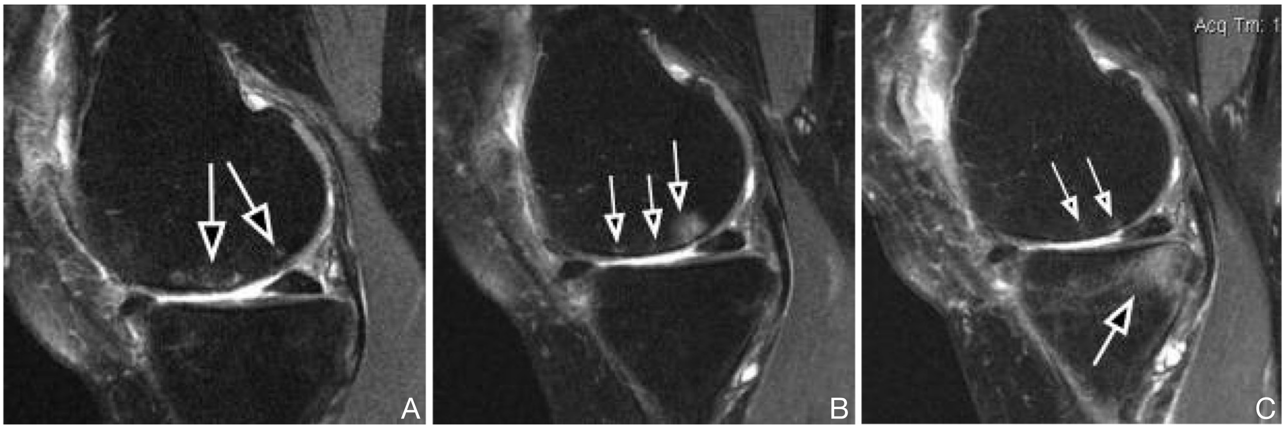

Fig. 3. Longitudinal evaluation of BMLs. Relevance of lesional vs. subregional scoring. (**A**) Baseline sagittal intermediate-weighted fat-suppressed MRI shows two distinct ill-defined BMLs at the central subregion of the medial femur (arrows). Overall lesion size in subregion qualifies as a grade 1 MOAKS/grade 2 WORMS lesion. (**B**) Follow-up MRI 1 year later shows within-grade increase in overall subregional lesion size in the same subregion. In contrast to image A, now three distinct lesions are observed (arrows). The single anterior lesion has split into two lesions with a decrease in lesion size, while the previous posterior lesion shows now an increase in lesion size. (**C**) Two-year follow-up MRI shows a decrease in overall femoral BML size with now a total subregional score of 1 using WORMS and MOAKS. There are two distinct lesions now with the most anterior lesion from image B showing complete regression. No cystic component of any of the lesions is observed. There is a large (grade 3 WORMS and MOAKS) incident lesion in the posterior medial tibia. BML, bone marrow lesion; MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; WORMS, Whole Organ Magnetic Resonance Score.

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.[13] 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 T_1-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.[12] 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.[1] 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.[12] 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.[1] 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

Table 1. Comparison of different semi-quantitative scoring system of knee osteoarthritis. Changes in MOAKS refer to original BLOKS and WORMS score

	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, media/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 • Score 1: subregional approach 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)]	Compared to BLOKS: • Score 1: same • 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: • Size: form 0 to 3, concerning percentage of subregional bone volume (thresholds, 10–85%). • Percentage of surface area adjacent to subchondral plate. • Percentage of BML that is noncystic	Summed BML for subregion Three aspects scored: • Size: from 0 to 3, concerning percentage of subregional bone volume (thresholds, 33–66%) • Percentage of surface area adjacent to subchondral bone omitted • Percentage of BML that is noncystic unchanged • Count number of lesions for subregion added
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

Table 1. *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 score	Synovial thickening described as present or absent on sagittal T_1W SPGR sequence (location not described)	A. Scoring of size of signal change in Hoffa's fat pad B. Five additional sites scored as present or absent (details of scoring not described)	Score of 0 to 3 applied to signal changes in Hoffa's fat pad. Feature renamed as "Hoffa-synovitis"
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	Cruciate ligaments and collateral ligaments scored as intact or torn	Not scored	Cruciate ligaments scored as normal or complete tear Associated insertional BMLs are scored in tibia and in femur Collateral ligaments not scored	Unchanged
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.[43,44] For example, WORMS meniscal scoring mixes multiple different constructs, while BLOKS clearly differentiates different tear types from intramensical 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.[26] 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,[45] and the OAI.4[46,47] 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.[25]

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[48] (Fig. 7). In fact, other conditions lead to similar changes such as chronic fibrotic changes.[48,49] It has been shown that only contrast-enhanced (CE) MRI-detected synovitis correlates with histological findings.[50,51] Therefore, CE-MRI is the only method that accurately assesses the true extent of synovitis in knee OA[52] (Fig. 8). Three different scoring systems to assess synovitis on the basis of CE-MRI have been published. The grading system developed by Guermazi et al.[53] 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.[54]

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

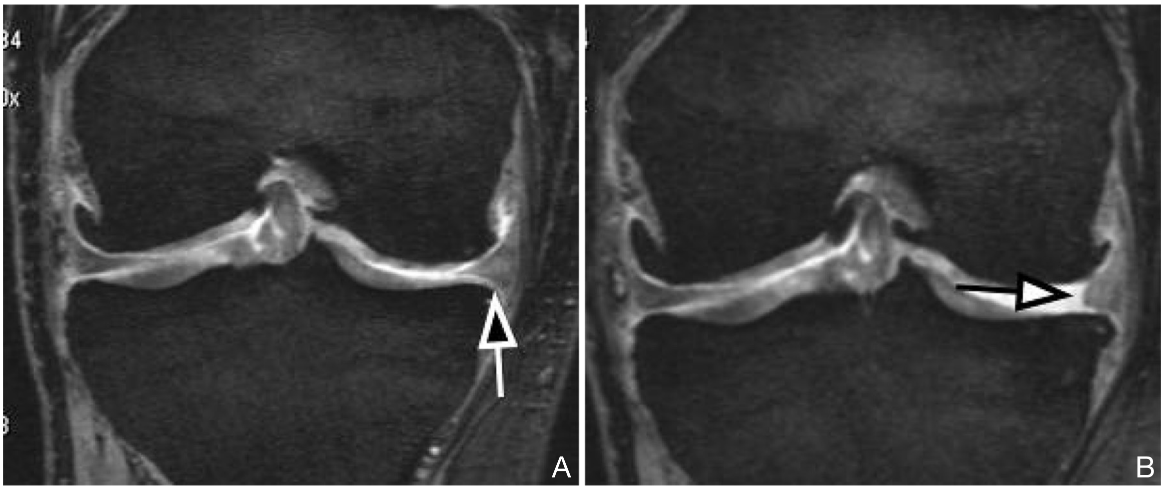

Fig. 4. Meniscal maceration is commonly observed in OA knees. (**A**) Baseline coronal dual echo at stead state (DESS) image shows a normal body of the medial meniscus without evidence of a tear of substance loss but little extrusion (arrow; grade 1 MOAKS). (**B**) Two years later, there is evidence of substance loss (arrow) in the central part of the body region (also referred to as the "white zone"). This finding is also termed partial meniscal maceration. MOAKS, Magnetic Resonance Imaging Osteoarthritis Knee Score, OA: osteoarthritis.

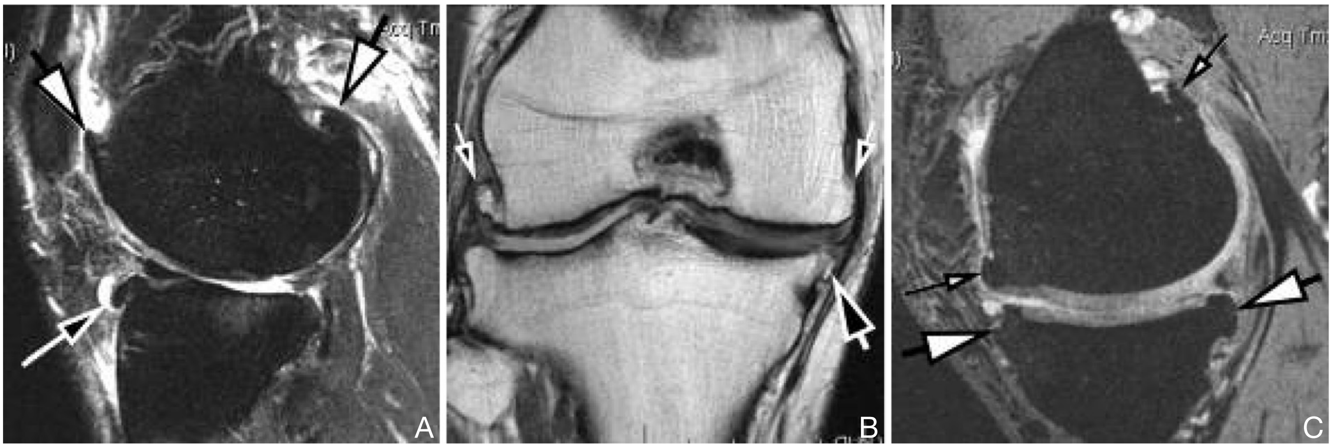

Fig. 5. Osteophytes are one of the hallmark features of OA on imaging and part of the disease definition on X-rays. While WORMS uses a complex approach of osteophytes scoring on a 0–7 scale at 16 articular anatomical locations, MOAKS applies a somewhat simplified scheme on a 0–3 scale at only 12 different 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 distension 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.

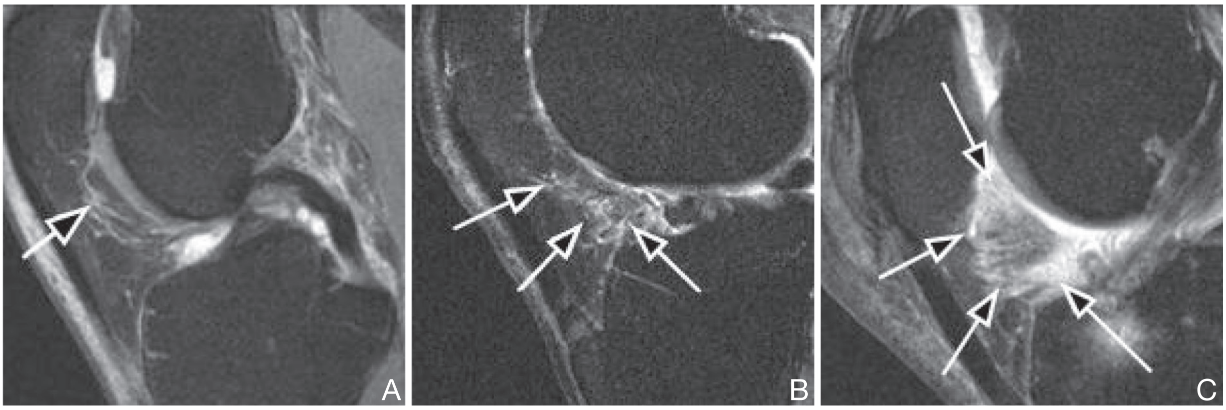

Fig. 7. Signal changes in Hoffa's fat pad are commonly used as a surrogate for synovitis on non-contrast-enhanced MRI. While these structural changes have been used for a long time they have not been described in the WORMS system but have been incorporated in the MOAKS system. Although synovitis can only be visualized directly on contrast-enhanced sequences, it has been shown that Hoffa's signal changes are a sensitive but non-specific surrogate of synovitis. (**A**) Sagittal proton density-weighted MRI shows a discrete ill-defined hyperintense signal alteration in Hoffa's fat pad consistent with grade 1 Hoffa-synovitis (arrow). (**B**) A grade 2 signal change within the fat pad is shown in this example (arrows). (**C**) Severe, grade 3 signal alterations almost occupying the entire fat pad are seen in this image (arrows). MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; WORMS, Whole Organ Magnetic Resonance Score.

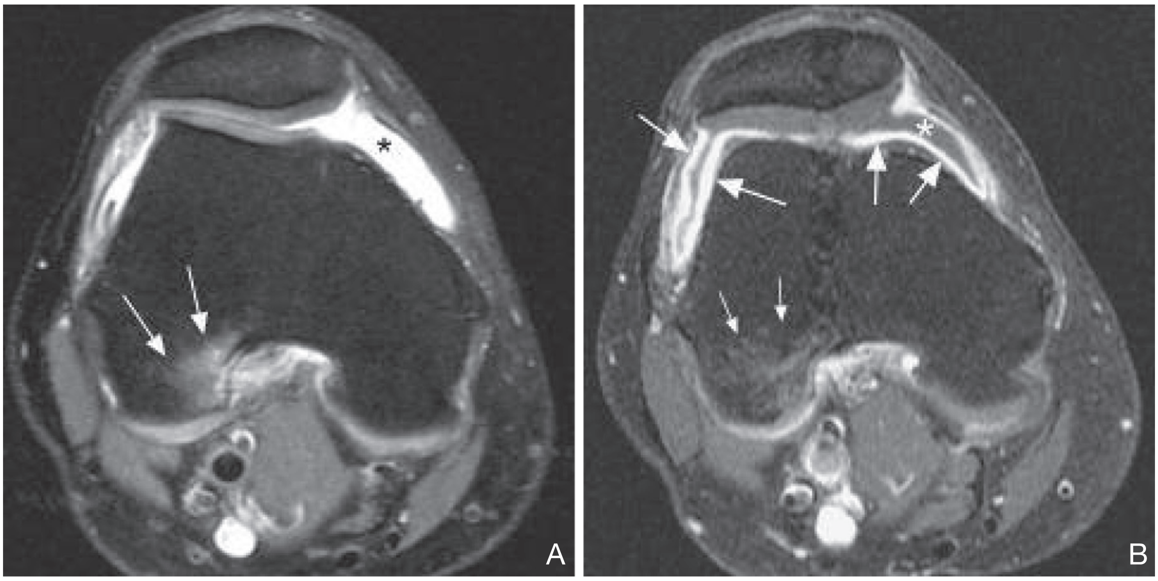

Fig. 8. Comparison of inflammatory manifestations of disease using non-enhanced and contrast-enhanced sequences. (**A**) Axial intermediate-weighted fat-suppressed MRI shows homogeneous hyperintensity within the joint cavity consistent with grade 2 effusion-synovitis by MOAKS and WORMS (asterisk). Note BML in the posterior lateral femoral condyle consistent with traction edema at the insertion of the anterior cruciate ligament (arrows). (**B**) Corresponding T_1-weighted fat-suppressed image after intravenous contrast administration clearly differentiates between intraarticular joint fluid depicted as hypointensity (asterisk) and true synovial thickening visualized as hyperintense contrast enhancement of the synovial membrane (large arrows). Note that BMLs are similarly depicted on T_2-weighted fat-suppressed and T_1-weighted contrast-enhanced fat-suppressed MRI (small arrows). BML, bone marrow lesion; MOAKS, MRI Osteoarthritis Knee Score; MRI: magnetic resonance imaging; 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.

Funding Statement

Frank W Roemer has shares in Boston Imaging Core Lab, LLC, a company providing image assessment services to academia and the pharmaceutical and medical device industry. Ali Guermazi receives honorary from Genzyme, TissueGene, OrthoTrophix, and

Merck Serono. He has shares in Boston Imaging Core Lab, LLC.

References

1. Roemer FW, Eckstein F, Guermazi A. Magnetic resonance imaging-based semiquantitative and quantitative assessment in osteoarthritis. Rheum Dis Clin North Am 2009; 35:521–555.
2. Eckstein F, Schnier M, Haubner M, et al. Accuracy of cartilage volume and thickness measurements with magnetic resonance imaging. Clin Orthop Relat Res 1998; (352):137–148.
3. Burgkart R, Glaser C, Hyhlik-Dürr A, Englmeier KH, Reiser M, Eckstein F. Magnetic resonance imaging-based assessment of cartilage loss in severe osteoarthritis: accuracy, precision, and diagnostic value. Arthritis Rheum 2001; 44:2072–2077.
4. Cicuttini F, Forbes A, Asbeutah A, Morris K, Stuckey S. Comparison and reproducibility of fast and conventional spoiled gradient-echo magnetic resonance sequences in the determination of knee cartilage volume. J Orthop Res 2000; 18:580–584.
5. Sowers MF, Hayes C, Jamadar D, et al. Magnetic resonance-detected subchondral bone marrow and cartilage defect characteristics associated with pain and X-ray-defined knee osteoarthritis. Osteoarthritis Cartilage 2003; 11:387–393.
6. Peterfy CG, Guermazi A, Zaim S, et al. Whole-Organ Magnetic Resonance Imaging Score (WORMS) of the knee in osteoarthritis. Osteoarthritis Cartilage 2004; 12:177–190.
7. Biswal S, Hastie T, Andriacchi TP, Bergman GA, Dillingham MF, Lang P. Risk factors for progressive cartilage loss in the knee: a longitudinal magnetic resonance imaging study in forty-three patients. Arthritis Rheum 2002; 46:2884–2892.
8. Zanetti M, Bruder E, Romero J, Hodler J. Bone marrow edema pattern in osteoarthritic knees: correlation between MR imaging and histologic findings. Radiology 2000; 215:835–840.
9. Pham XV, Monteiro I, Judet O, et al. Magnetic resonance imaging changes in periarticular soft tissues during flares of medial compartment knee osteoarthritis. Preliminary study in 10 patients. Rev Rhum Engl Ed 1999; 66:398–403.
10. Gale DR, Chaisson CE, Totterman SM, Schwartz RK, Gale ME, Felson D. Meniscal subluxation: association with osteoarthritis and joint space narrowing. Osteoarthritis Cartilage 1999; 7:526–532.
11. Hill CL, Gale DG, Chaisson CE, et al. Knee effusions, popliteal cysts, and synovial thickening: association with knee pain in osteoarthritis. J Rheumatol 2001; 28:1330–1337.
12. Hunter DJ, Lo GH, Gale D, Grainger AJ, Guermazi A, Conaghan PG. The reliability of a new scoring system for knee osteoarthritis MRI and the validity of bone marrow lesion assessment: BLOKS (Boston Leeds Osteoarthritis Knee Score). Ann Rheum Dis 2008; 67:206–211.
13. Kornaat PR, Ceulemans RY, Kroon HM, et al. MRI assessment of knee osteoarthritis: Knee Osteoarthritis Scoring System (KOSS)—inter-observer and intra-observer reproducibility of a compartment-based scoring system. Skeletal Radiol 2005; 34:95–102.
14. Hunter DJ, Zhang YQ, Niu JB, et al. The association of meniscal pathologic changes with cartilage loss in symptomatic knee osteoarthritis. Arthritis Rheum 2006; 54:795–801.
15. Hernández-Molina G, Neogi T, Hunter DJ, et al. The association of bone attrition with knee pain and other MRI features of osteoarthritis. Ann Rheum Dis 2008; 67:43–47.
16. Felson DT, McLaughlin S, Goggins J, et al. Bone marrow edema and its relation to progression of knee osteoarthritis. Ann Intern Med 2003; 139(5 Pt 1):330–336.
17. Felson DT, Niu J, Guermazi A, et al. Correlation of the development of knee pain with enlarging bone marrow lesions on magnetic resonance imaging. Arthritis Rheum 2007; 56:2986–2992.
18. Englund M, Guermazi A, Gale D, et al. Incidental meniscal findings on knee MRI in middle-aged and elderly persons. N Engl J Med 2008; 359:1108–1115.
19. Englund M, Guermazi A, Roemer FW, et al. Meniscal tear in knees without surgery and the development of radiographic osteoarthritis among middle-aged and elderly persons: The Multicenter Osteoarthritis Study. Arthritis Rheum 2009; 60:831–839.
20. Hunter DJ, Zhang YQ, Tu X, et al. Change in joint space width: hyaline articular cartilage loss or alteration in meniscus? Arthritis Rheum 2006; 54:2488–2495.
21. Roemer FW, Guermazi A, Javaid MK, et al. Change in MRI-detected subchondral bone marrow lesions is associated with cartilage loss: the MOST Study. A longitudinal multicentre study of knee osteoarthritis. Ann Rheum Dis 2009; 68:1461–1465.
22. Roemer FW, Felson DT, Yang T, et al. The association between meniscal damage of the posterior horns and localized posterior synovitis detected on T1-weighted contrast-enhanced MRI—the MOST study. Semin Arthritis Rheum 2013; 42:573–581.
23. Roemer FW, Guermazi A, Hunter DJ, et al. The association of meniscal damage with joint effusion in persons without radiographic osteoarthritis: the Framingham and MOST osteoarthritis studies. Osteoarthritis Cartilage 2009; 17:748–753.
24. Reichenbach S, Yang M, Eckstein F, et al. Does cartilage volume or thickness distinguish knees with and without mild radiographic osteoarthritis? The Framingham Study. Ann Rheum Dis 2010; 69:143–149.
25. Roemer FW, Kwoh CK, Hannon MJ, et al. Can structural joint damage measured with MR imaging be used to predict knee replacement in the following year? Radiology 2015; 274:810–820.

26. Hunter DJ, Guermazi A, Lo GH, et al. Evolution of semi-quantitative whole joint assessment of knee OA: MOAKS (MRI Osteoarthritis Knee Score). Osteoarthritis Cartilage 2011; 19:990–1002.
27. Guermazi A, Roemer FW, Haugen IK, Crema MD, Hayashi D. MRI-based semiquantitative scoring of joint pathology in osteoarthritis. Nat Rev Rheumatol 2013; 9:236–251.
28. Roemer FW, Guermazi A, Lynch JA, et al. Short tau inversion recovery and proton density-weighted fat suppressed sequences for the evaluation of osteoarthritis of the knee with a 1.0 T dedicated extremity MRI: development of a time-efficient sequence protocol. Eur Radiol 2005; 15:978–987.
29. Peterfy CG, Gold G, Eckstein F, Cicuttini F, Dardzinski B, Stevens R. MRI protocols for whole-organ assessment of the knee in osteoarthritis. Osteoarthritis Cartilage 2006; 14 Suppl A:A95–A111.
30. Roemer FW, Kwoh CK, Hannon MJ, et al. Semiquantitative assessment of focal cartilage damage at 3T MRI: a comparative study of dual echo at steady state (DESS) and intermediate-weighted (IW) fat suppressed fast spin echo sequences. Eur J Radiol 2011; 80:e126–e131.
31. Hayashi D, Guermazi A, Kwoh CK, et al. Semiquantitative assessment of subchondral bone marrow edema-like lesions and subchondral cysts of the knee at 3T MRI: a comparison between intermediate-weighted fat-suppressed spin echo and Dual Echo Steady State sequences. BMC Musculoskelet Disord 2011; 12:198.
32. Hayashi D, Roemer FW, Guermazi A. Choice of pulse sequences for magnetic resonance imaging-based semi-quantitative assessment of cartilage defects in osteoarthritis research: comment on the article by Doré et al. Arthritis Rheum 2010; 62:3830–3831; author reply 3831–3832.
33. Jarraya M, Hayashi D, Guermazi A, et al. Susceptibility artifacts detected on 3T MRI of the knee: frequency, change over time and associations with radiographic findings: data from the joints on glucosamine study. Osteoarthritis Cartilage 2014; 22:1499–1503.
34. Peterfy CG, Schneider E, Nevitt M. The osteoarthritis initiative: report on the design rationale for the magnetic resonance imaging protocol for the knee. Osteoarthritis Cartilage 2008; 16:1433–1441.
35. Gold GE, Cicuttini F, Crema MD, et al. OARSI Clinical Trials Recommendations: Hip imaging in clinical trials in osteoarthritis. Osteoarthritis Cartilage 2015; 23: 716–731.
36. Crema MD, Nogueira-Barbosa MH, Roemer FW, et al. Three-dimensional turbo spin-echo magnetic resonance imaging (MRI) and semiquantitative assessment of knee osteoarthritis: comparison with two-dimensional routine MRI. Osteoarthritis Cartilage 2013; 21:428–433.
37. Hunter DJ, Zhang W, Conaghan PG, et al. Responsiveness and reliability of MRI in knee osteoarthritis: a meta-analysis of published evidence. Osteoarthritis Cartilage 2011; 19:589–605.
38. Stahl R, Jain SK, Lutz J, et al. Osteoarthritis of the knee at 3.0 T: comparison of a quantitative and a semi-quantitative score for the assessment of the extent of cartilage lesion and bone marrow edema pattern in a 24-month longitudinal study. Skeletal Radiol 2011; 40:1315–1327.
39. Roemer FW, Nevitt MC, Felson DT, et al. Predictive validity of within-grade scoring of longitudinal changes of MRI-based cartilage morphology and bone marrow lesion assessment in the tibio-femoral joint—the MOST study. Osteoarthritis Cartilage 2012; 20: 1391–1398.
40. Eckstein F, Guermazi A, Gold G, et al. Imaging of cartilage and bone: promises and pitfalls in clinical trials of osteoarthritis. Osteoarthritis Cartilage 2014; 22:1516–1532.
41. Amin S, Guermazi A, Lavalley MP, et al. Complete anterior cruciate ligament tear and the risk for cartilage loss and progression of symptoms in men and women with knee osteoarthritis. Osteoarthritis Cartilage 2008; 16:897–902.
42. Reichenbach S, Guermazi A, Niu J, et al. Prevalence of bone attrition on knee radiographs and MRI in a community-based cohort. Osteoarthritis Cartilage 2008; 16:1005–1010.
43. Felson DT, Lynch J, Guermazi A, et al. Comparison of BLOKS and WORMS scoring systems part II. Longitudinal assessment of knee MRIs for osteoarthritis and suggested approach based on their performance: data from the Osteoarthritis Initiative. Osteoarthritis Cartilage 2010; 18:1402–1407.
44. Lynch JA, Roemer FW, Nevitt MC, et al. Comparison of BLOKS and WORMS scoring systems part I. Cross sectional comparison of methods to assess cartilage morphology, meniscal damage and bone marrow lesions on knee MRI: data from the osteoarthritis initiative. Osteoarthritis Cartilage 2010; 18:1393–1401.
45. Katz JN, Brophy RH, Chaisson CE, et al. Surgery versus physical therapy for a meniscal tear and osteoarthritis. N Engl J Med 2013; 368:1675–1684.
46. Eckstein F, Wirth W, Nevitt MC. Recent advances in osteoarthritis imaging—the osteoarthritis initiative. Nat Rev Rheumatol 2012; 8:622–630.
47. Roemer FW, Kwoh CK, Hannon MJ, et al. What comes first? Multitissue involvement leading to radiographic osteoarthritis: magnetic resonance imaging-based trajectory analysis over four years in the osteoarthritis initiative. Arthritis Rheumatol 2015; 67:2085–2096.
48. Roemer FW, Guermazi A, Zhang Y, et al. Hoffa's fat pad: evaluation on unenhanced MR images as a measure of patellofemoral synovitis in osteoarthritis. AJR Am J Roentgenol 2009; 192:1696–1700.
49. Saddik D, McNally EG, Richardson M. MRI of Hoffa's fat pad. Skeletal Radiol 2004; 33:433–444.
50. Loeuille D, Rat AC, Goebel JC, et al. Magnetic resonance imaging in osteoarthritis: which method best reflects synovial membrane inflammation? Correlations

with clinical, macroscopic and microscopic features. Osteoarthritis Cartilage 2009; 17:1186–1192.
51. Loeuille D, Sauliere N, Champigneulle J, Rat AC, Blum A, Chary-Valckenaere I. Comparing non-enhanced and enhanced sequences in the assessment of effusion and synovitis in knee OA: associations with clinical, macroscopic and microscopic features. Osteoarthritis Cartilage 2011; 19:1433–1439.
52. Hayashi D, Roemer FW, Katur A, et al. Imaging of synovitis in osteoarthritis: current status and outlook. Semin Arthritis Rheum 2011; 41:116–130.
53. Guermazi A, Roemer FW, Hayashi D, et al. Assessment of synovitis with contrast-enhanced MRI using a whole-joint semiquantitative scoring system in people with, or at high risk of, knee osteoarthritis: the MOST study. Ann Rheum Dis 2011; 70:805–811.
54. Guermazi A, Hayashi D, Roemer FW, et al. Synovitis in knee osteoarthritis assessed by contrast-enhanced magnetic resonance imaging (MRI) is associated with radiographic tibiofemoral osteoarthritis and MRI-detected widespread cartilage damage: the MOST study. J Rheumatol 2014; 41:501–508.