

Imaging of knee osteoarthritis: data beyond the beauty

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Purpose of review

MRI has revolutionized osteoarthritis research by providing semi-quantitative and quantitative imaging endpoints on most articular tissues. With the first image data of the Osteoarthritis Initiative now becoming publicly available, this article reviews recent developments in quantitative imaging of osteoarthritis.

Recent findings

Although radiography remains the standard for regulatory studies on disease modifying osteoarthritis drugs, there is no consensus on the optimal positioning and acquisition protocol. With MRI, semi-quantitative scoring systems for evaluation of multiple articular tissue changes have been developed and are currently investigated in the context of correlation with symptoms and of predicting structural progression of osteoarthritis. Most efforts on quantitative measurement of imaging endpoints have focused on cartilage morphology and composition, with higher field strength (3T), newer sequences, and new measurement endpoints being a driver of current innovation.

Summary

The semi-quantitative and quantitative tools for analysis of articular structure are now available and permit comprehensive analysis of morphological and compositional tissue changes in osteoarthritis. These changes will need to be related to clinical outcomes (e.g. how a patient feels or functions) with current epidemiological studies, such as the Osteoarthritis Initiatives, providing the opportunity for clinical validation of these imaging biomarkers.

Keywords

clinical outcome, diarthrodial joint, MRI, osteoarthritis

Abbreviations

BML	bone marrow lesion
dGEMRIC	delayed gadolinium-enhanced MRI of cartilage
DMOAD	disease-modifying osteoarthritis drug
GAG	glycosaminoglycan
JSN	joint space narrowing
OAI	Osteoarthritis Initiative
SPGR	spoiled gradient echo
WORMS	Whole-Organ Magnetic Resonance Imaging Score

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Introduction

MRI has made a fundamental impact on osteoarthritis research by providing the opportunity to determine semiquantitative or quantitative imaging endpoints of most articular tissues. This is of particular interest for characterizing the risk factors for osteoarthritis in epidemiological studies and for the evaluation of disease (structure) modifying therapy (disease-modifying osteoarthritis drugs; DMOADs) efficacy in osteoarthritis, which has so far not been approved by regulatory agencies. With the first imaging data of the Osteoarthritis Initiative (OAI; website: <http://www.niams.nih.gov/ne/oi/>) now becoming publicly available, this article reviews recent developments in quantitative imaging of osteoarthritis, including radiography, semi-quantitative scoring of magnetic resonance (MR) images, and quantitative measurement of articular cartilage morphology and composition in osteoarthritis.

Radiography

Radiography is the technique currently accepted by regulatory agencies for evaluating DMOADs, but currently no consensus exists on the optimal positioning and acquisition protocol [1–3,4[•],5^{••}]. Radiography is limited by projectional errors [5^{••},6], and joint space narrowing (JSN) is influenced not only by cartilage, but also by meniscal status [7,8,9^{••}]. Le Graverand *et al.* [5^{••}] reported that in 80 persons with knee osteoarthritis near-parallel alignment of the tibial plateau was achieved more frequently with a fluoroscopically guided semi-flexed anterior–posterior protocol than with a nonfluoroscopic fixed flexion or metatarso-phalangeal (MTP) protocol. Paired radiographs with near-parallel alignment showed more rapid and less variable JSN than the total cohort. In another comparative study [4[•]], fluoroscopic guided radiography showed a greater magnitude and lower standard deviation of JSN (0.42 mm) than fixed

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flexion (0.63mm) or MTP (0.53 mm). There was, however, insufficient power to control for differences in study durations and inclusion criteria. With this level of imprecision and lack of ability to exclusively monitor one target tissue, radiography has inherent limitations in epidemiological and DMOAD studies.

Semi-quantitative scoring of MRI

Traditionally, osteoarthritis has been considered a disease of articular cartilage. During a US National Institutes of Health workshop, 'Consensus on osteoarthritis imaging', in Bethesda [10], experts still ranked articular cartilage to be the most important MRI feature of osteoarthritis severity and progression, but osteophytes, bone marrow lesions (BMLs), synovitis, meniscal abnormality and synovial effusion were also considered important [10]. The current concept holds that osteoarthritis involves the entire joint organ (Fig. 1) [11[•]].

Semi-quantitative scoring of the knee relies on an observer to score a variety of features believed to be relevant to the functional integrity of the joint or potentially involved in the pathophysiology of osteoarthritis. A number of semi-quantitative whole-organ scoring methods have been developed and tested [12–15]. MR sequences for semi-quantitative scoring vary depending on the target tissue of interest, scanner type, and investigator preference, but the Bethesda NIH imaging workshop [16[•]] and the imaging working group of the OAI have recently made recommendations on sequences that will capture most of the information for scoring tissue in the whole knee in osteoarthritis (website: <http://www.oai.ucsf.edu/datarelease/About.asp>).

The importance of using validated observers and instruments was highlighted by a study [17[•]] that reported an accuracy of only 52% for medial meniscus and of 77% for cartilage lesions, when rated by independent imaging institutions rather than musculoskeletal MRI specialists; 37% of the operations supported by MRI were reported as unjustified [17[•]]. Conaghan *et al.* [18[•]] evaluated the internal construct validity of the semi-quantitative Whole-Organ Magnetic Resonance Imaging Score (WORMS) [12] in two osteoarthritis cohorts by applying a Rasch model. Because few of the subscales met the

Figure 1 Illustrative examples of disease changes occurring in multiple different tissues

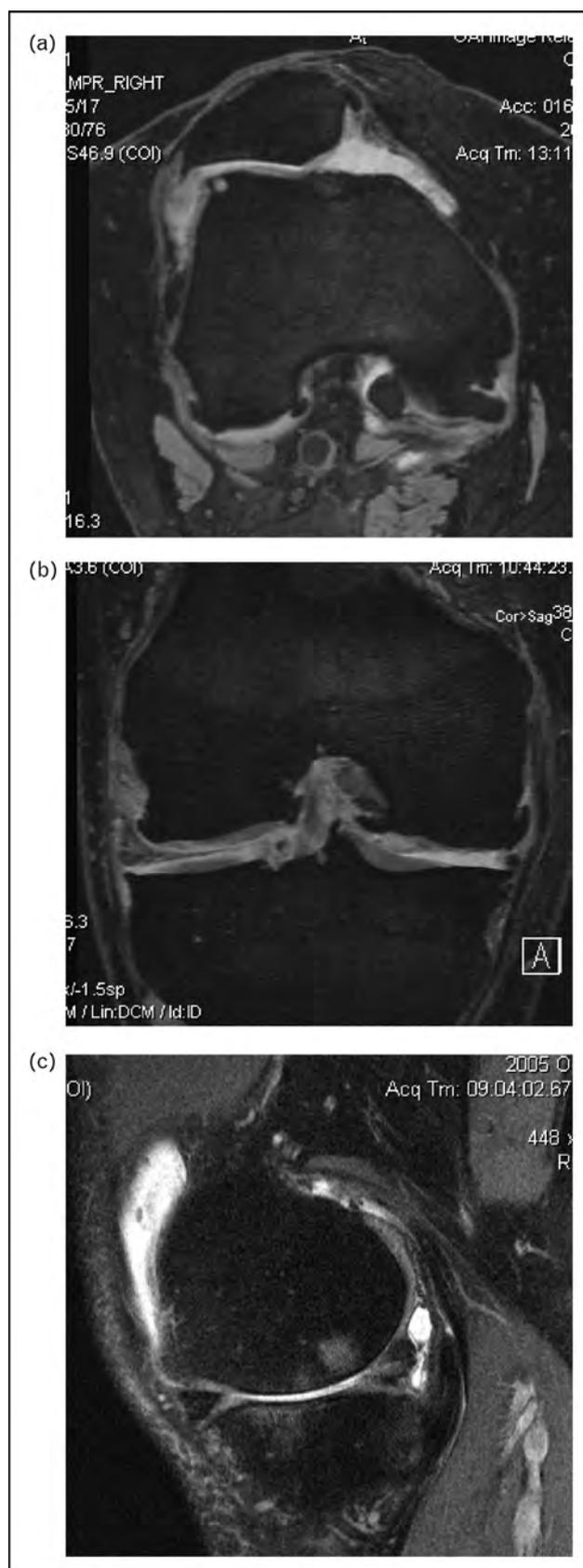


Figure 1

The images were obtained from the Osteoarthritis Initiative (OAI) database, which is available for public access at <http://www.oai.ucsf.edu/>. The specific datasets used are from image release OB1 and 1B1. (a) Axial image depicting moderate effusion, medial and lateral patella and posterior femoral osteophytes, full thickness cartilage loss and cysts in the lateral trochlea. (b) Coronal double echo steady state (DESS) image depicting full thickness cartilage loss on the medial tibia and femur, osteophytes and the macerated remnants of medial meniscus. (c) Sagittal fat suppressed image depicting full thickness cartilage loss in central weight bearing portions of the tibia and femur and bone marrow lesions in the medial femur and tibia, and moderate sized effusion.

requirements of the model, constructing outcome measurements that sum different features of complex pathological structural change throughout several anatomical sites is problematic [18[•]]. These studies have prompted the re-evaluation of current scoring schemes and development of novel scoring methods.

Recent applications of semi-quantitative scores have started to cast light on symptom etiology and disease etiopathogenesis of osteoarthritis. Earlier studies reported that all [19] or larger BMLs are associated with pain [20], but other studies have failed to show such relationships [21]. Kornaat *et al.* [22^{••}] recently reported that synovial effusion and patellofemoral osteophytes, but not cartilage abnormalities, BMLs, or other structural changes were related to pain. Another study found knee pain severity to be associated with subarticular bone attrition, BMLs, synovitis/effusion, and meniscal tears [23^{••}], when using WOMBS for the worst compartment. The contribution of BMLs to pain severity appeared to require the presence of bone attrition [23^{••}].

Meniscal position was found to be correlated with meniscus damage [24[•]] and both were identified to predict progression of cartilage lesions in MRI. BMLs were found to infrequently regress [25[•]] and an increase in their size was correlated with cartilage loss. BML location and change in size was mediated by alignment [25[•]]. Further work with standardized and valid measures in larger samples will be required to elucidate which of these structural abnormalities are associated with current or prospective symptoms or subsequent cartilage loss.

One study evaluated the responsiveness of whole organ scoring (WORMS) [12] and cartilage volume change in 150 subjects with knee osteoarthritis from a randomized, double-blind trial at baseline and 6-month follow-up [26^{••}]. Of all features measured, cartilage morphology, synovitis and osteophytes appeared to be the most responsive, but the effect size and smallest detectable differences were found to be very small.

Quantitative measurement of articular cartilage morphology with MRI

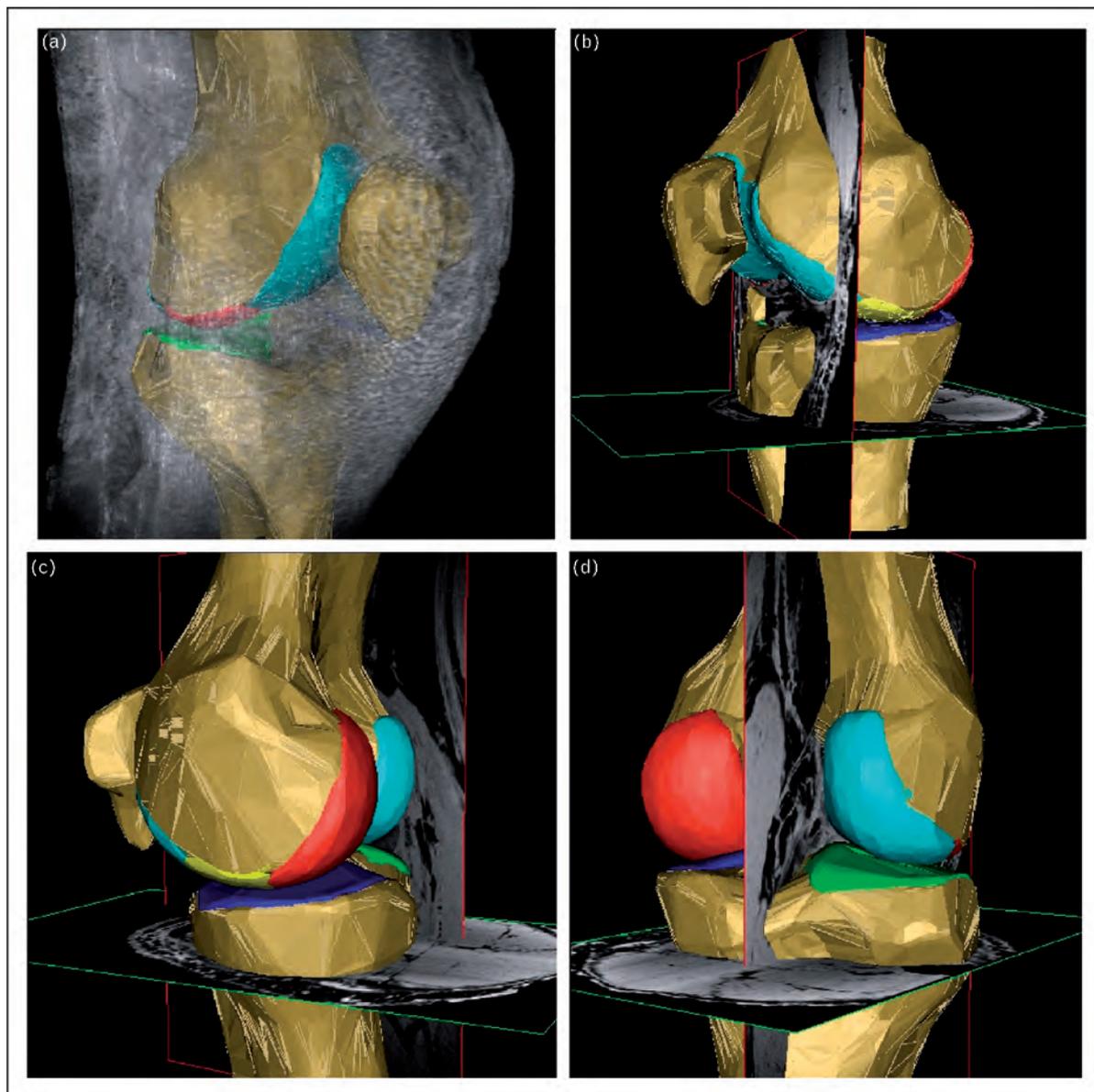
Because structural changes in osteoarthritis may be very subtle and slow, quantitative measurement of articular structures throughout contiguous MR images may reveal changes that are not apparent during scoring. Amongst joint tissues, articular cartilage has received most of the attention (Fig. 2). Water-excitation T1-weighted spoiled gradient echo (SPGR) imaging at 1.5 T represents the current gold standard sequence for quantitative measurement of cartilage morphology [16[•],27,28[•]], but more efficient sequences [29] and imaging systems (up to 7 T [30[•]]) have recently become available. Three Tesla cartilage imaging has been validated and shown to reduce

precision errors compared with 1.5 T [31,32^{••}]; results from different vendors have shown to be comparable at 3 T [33]. Peripheral 1.0 T scanners have also been cross-calibrated versus 1.5 T cartilage measurement [34], as these potentially permit more widespread application of this technology. Precision errors, however, were found to be somewhat higher than at 1.5 T [34].

Most investigations on cartilage morphology have focused on cartilage volume (changes), but this has inherent limitations as an outcome measure. Subjects with larger bones display larger cartilage volume, limiting the ability to discriminate between osteoarthritis patients and normals [35]. Women have smaller joint surfaces than men (and hence also cartilage volume), even after adjustment for body height and weight [36]. In longitudinal studies, the subchondral bone area increases by about 1% with normal aging, consistent with theories of metaphyseal expansion [37]. Such effects may mask longitudinal reduction in cartilage thickness, if only cartilage volume is measured. To provide a uniform nomenclature in scientific communications, an international group of experts has proposed how morphological and composition parameters of cartilage should be named and defined, and which minimal methodological information should be described [38^{••}].

The OAI (website: <http://www.niams.nih.gov/nc/oi/>) is a 4-year observational study in over 4000 patients, targeted at identifying the most reliable and sensitive biomarkers for evaluating the development and progression of symptomatic knee osteoarthritis. The first results from OAI pilot studies have been published. One study has compared near-isotropic, sagittal double echo steady state (DESS) [39], a sequence with greater T2-weighting, with previously validated coronal SPGR [32^{••}]. The DESS displayed similar test–retest precision of femorotibial cartilage morphology, but precision errors in the femoropatellar joint were higher than those previously published for sagittal SPGR [40]. Another study [41[•]] reported that, despite the higher signal-to-noise ratio of the cartilage achieved with phase array coils, these did not translate into lower precision errors compared with quadrature knee coil measurements.

Reports on longitudinal changes of cartilage morphology [28[•],42–44,45^{••},46,47,48^{••},49^{••},50[•]] have varied substantially between studies (0–7% annually). A meta-analysis of available data reported annual changes of 4–6% in most knee compartments [28[•]]. Estimates of annual cartilage loss over 2 years were found consistent with those over 4.5 years in the same cohort, indicating that 2-year change predicts long-term cartilage loss [45^{••}]. Medial tibial cartilage loss was associated with lesser severity of baseline knee pain, but was independent of age, BMI and other factors [45^{••}]. Raynauld *et al.*

Figure 2 Reconstruction of the knee from magnetic resonance images with segmented cartilage plates displayed in colour

Blue shows medial tibial cartilage (MT); green, lateral tibial cartilage (LT); yellow, central (weight-bearing) medial femoral cartilage (cMF); red, central (weight-bearing) lateral femoral cartilage (cLF) and posterior medial femoral cartilage (pMF); turquoise, posterior lateral femoral cartilage (pLF) and trochlear femoral cartilage (TrF). (a) View from antero-lateral direction with soft tissues shown in grey. (b) View from antero-medial direction with coronal and axial multiplanar reconstructions of the original magnetic resonance images being displayed. (c) View from posteromedial direction with axial multiplanar reconstructions and an original sagittal magnetic resonance image being displayed. (d) View from posterior direction with axial multiplanar reconstructions and an original sagittal magnetic resonance image being displayed.

[48^{••}] reported cartilage volume changes in 107 patients with knee osteoarthritis to be $-5.5 \pm 4.3\%$ in the medial compartment at 12 months, and $-8.3 \pm 6.5\%$ at 24 months. The rate of change was associated with meniscal extrusion and tears, bone marrow edema and high BMI. No association was found with JSN (radiographs) or urine biomarker levels [48^{••}]. Other studies also found only weak correlations between MRI and radiographic change [46,50[•],51].

When evaluating the effects of misalignment, relatively small changes in cartilage thickness ($<1.5\%$ per annum) were found in subjects with a neutral knee axis [52]. Higher rates of change were reported in the medial knee compartment with varus ($-3.1 \pm 4.0\%$), and in the lateral knee compartment with valgus malalignment ($-2.9 \pm 4.3\%$), whereas opposite compartments displayed no significant change, respectively. In a nonosteoarthritic cohort, in contrast, baseline knee alignment was not

associated with subsequent cartilage volume loss or progression of chondral defects [53]. Approaches for determining subregional cartilage thickness have shown promise for more sensitive detection of structural change than analysis of entire cartilage plates [54–56].

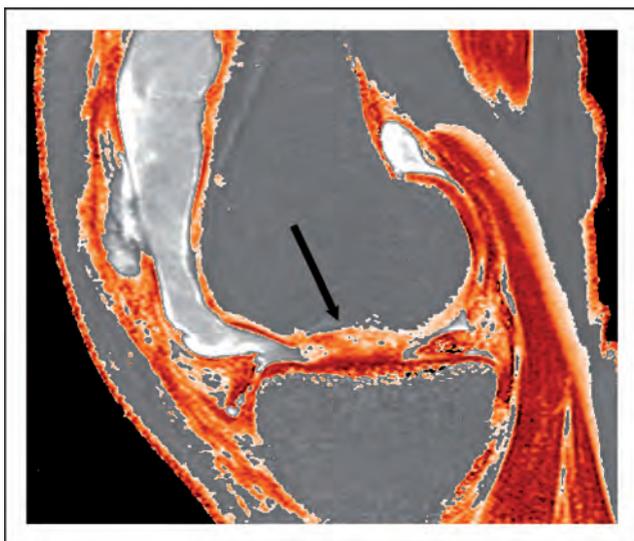
Studies on how cartilage loss relates to symptoms have produced contradictory results [46,55,57–59]. One study, however, reported that the rate of cartilage loss over 2 years was associated with a clinical endpoint (risk of receiving knee arthroplasty 2 years later) [60]. The OAI and other large trials will soon make it possible to relate longitudinal changes of cartilage to clinical outcome.

Quantitative measurement of articular cartilage composition with MRI

While quantitative measurement of morphology can be used to monitor loss of cartilage tissue, there is also great interest in using MRI to detect changes that precede gross tissue degradation. Applications of parametric mapping techniques sensitive to early cartilage damage have been addressed in recent reviews [49•,61–64].

For research applications, the quantitative measurement of the cartilage transverse relaxation time (T₂) provides a potential imaging biomarker to identify and monitor structural changes in the collagen matrix (Fig. 3) [65]. Perturbation of the collagen architecture leads to increased T₂-weighted signal intensity; however, sites of decreased signal intensity can be observed adjacent to

Figure 3 Cartilage T₂ map of 23-year-old woman 3 months following autologous chondrocyte implantation of the medial femoral condyle



Repair tissue indicated by arrow demonstrates heterogeneously elevated cartilage T₂ with absence of normal spatial variation in T₂ seen in normal cartilage.

sites of focal cartilage injury [66]. The majority of cartilage T₂ mapping studies used conventional multislice multi spin echo (MSME) sequences, typically with a minimum of seven echoes. Although fewer echoes have been used, there is theoretical concern that T₂ measurements obtained using only two echoes are prone to large error due to under sampling of the T₂ decay curve, artifact from stimulated echoes, and error due to variability in image signal to noise. Using a 1.5 T magnet and turbo spin echo (TSE) MSME sequence with eight echoes, the precision error was 3–7% and 6–29% for global and regional patellar cartilage T₂, respectively [67•]. While potentially more efficient in measuring T₂, these TSE or fast spin echo techniques have not yet been validated.

While increased cartilage T₂ is associated with an increase in water content [68] and a decrease in collagen content [69], the dominant factor influencing regional variation in T₂ is the anisotropic arrangement of the type II collagen matrix [70,71]. There is a strong inverse correlation of fiber anisotropy determined with polarized light microscopy and cartilage T₂ [72]. This sensitivity to collagen architecture has been used to identify maturational changes in the collagen matrix of osteochondral plugs from juvenile animals [73•,74]. A recent study of asymptomatic humans confirmed an age dependent increase in T₂ in adult cartilage [75]. Prior studies using depth resolved cartilage T₂ mapping demonstrated an age-dependent elevation in T₂, initially near the articular surface, and progressing to deeper layer with increasing age [76,77]. These studies have indicated that cartilage T₂ mapping provides a noninvasive endpoint that is sensitive to developmental and senescent changes in the collagen matrix that could be useful for future studies on human cartilage development and aging. Initial results in osteoarthritis were mixed, with some studies observing discrete differences of T₂ between control and osteoarthritis populations [78,79] whereas others did not [80,81].

The delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) technique relies on preferential distribution of the MRI contrast agent GdDTPA²⁻ into cartilage with low glycosaminoglycan content [82,83]. To adjust for differences in biodistribution of GdDTPA²⁻, the dose should be adjusted for BMI [84]. Although initial dGEMRIC techniques were limited to single slice acquisition, rapid three-dimensional applications of dGEMRIC that provide greater coverage and faster imaging times are currently undergoing validation [85,86]. Preliminary clinical applications of dGEMRIC for identification of early cartilage damage in the hip [87,88] have been promising. In a recent prospective study, low dGEMRIC scores indicative of low cartilage glycosaminoglycan (GAG) content were predictive of poor outcome in periacetabular osteoplasties for hip dysplasia [89•].

Using a combination of T2 mapping and dGEMRIC parameters, it is possible to estimate biomechanical properties of cartilage tissue [90], which may provide insight for guiding cartilage repair [91]. Both cartilage T2 mapping and dGEMRIC have been used for evaluation of reparative tissue following surgical repair of focal cartilage defects [92–94]. Longer heterogeneous T2 values were observed in repair tissue following autologous chondrocyte implantation (ACI) [95**]. The dGEMRIC scores in repair tissue were similar to those observed in normal cartilage, suggesting replenishment of GAG 10–15 months after ACI [95**]. Following arthroscopic osteochondral autograft transplantation (OAT), the normal decrease in cartilage T2 with respect to depth from the articular surface was predictive of hyaline cartilage histology, while heterogeneous T2 values were indicative of fibrocartilage repair tissue [96**]. Additional studies are needed to determine if parametric mapping techniques are prognostic of clinical outcome, or could replace arthroscopic biopsy for monitoring repair tissue histology.

T1rho is another emerging technique for evaluating GAG [97], but has also been shown to be sensitive to collagen [69]. Recent development of a rapid three-dimensional T1rho technique has been demonstrated in proof of concept studies [98*,99]. Although less widely available than T2 mapping studies, initial evaluation in a small number of subjects suggest it may be more responsive to cartilage damage associated with osteoarthritis [79,100*].

Conclusion

MRI holds considerable promise to become an invaluable tool in osteoarthritis epidemiology research and the development of structure modifying therapy. Sequences for 'whole organ assessment' and quantitative measurement of cartilage morphology are readily available on state-of-the-art 1.5 T and 3.0 T clinical scanners and have been validated. Quantitative data on cartilage composition are emerging and hold promise to detect osteoarthritis changes early. An important question to address is the relationship of these new imaging biomarkers with clinical endpoints and whether use of DMOADs has potential clinical benefits. Therefore, future research must focus on the question of whether structural (imaging) changes represent valid surrogate markers of clinical outcomes several years later. Ongoing initiatives in enhancing measurement methods and the availability of richer data resources should facilitate rapid advances in our understanding of this pervasive condition in coming years and to develop effective disease modifying therapy.

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References and recommended reading

Papers of particular interest, published within the annual period of review, have been highlighted as:

- of special interest
- of outstanding interest

Additional references related to this topic can also be found in the Current World Literature section in this issue (pp. 511–512).

- 1 Nevitt MC, Sharma L. OMERACT workshop radiography session 1. Osteoarthritis Cartilage 2006; 14 (Suppl A):A4–A9.
 - 2 Rovati LC, Pavelka K, Giacobelli G, *et al.* Assessment of joint space narrowing with conventional standing antero-posterior radiographs: relief in mild-to-moderate pain is not a confounder in recent osteoarthritis structure-modifying drug trials. Osteoarthritis Cartilage 2006; 14 (Suppl A):A14–A18.
 - 3 Buckland-Wright C. Review of the anatomical and radiological differences between fluoroscopic and nonfluoroscopic positioning of osteoarthritic knees. Osteoarthritis Cartilage 2006; 14 (Suppl A):A19–A31.
 - 4 Cline GA, Meyer JM, Stevens R, *et al.* Comparison of fixed flexion, fluoroscopic semi-flexed and MTP radiographic methods for obtaining the minimum medial joint space width of the knee in longitudinal osteoarthritis trials. Osteoarthritis Cartilage 2006; 14 (Suppl A):A32–A36.
- This was one of the few studies comparing different radiographic protocols, but was limited by the fact that techniques were applied to different cohorts. Fluoroscopic guided radiography, however, showed a greater magnitude and lower standard deviation of joint space narrowing (higher standardized response mean) than nonfluoroscopic techniques (fixed flexion or metatarso-phalangeal).
- 5 Le Graverand MP, Mazzuca S, Lassere M, *et al.* Assessment of the radiographic anatomic positioning of the osteoarthritic knee in serial radiographs: comparison of three acquisition techniques. Osteoarthritis Cartilage 2006; 14 (Suppl A):A37–A43.
- This study reported that paired radiographs with near-parallel alignment showed a higher standardized response mean for joint space narrowing than those without, and that near-parallel alignment of the tibial plateau was achieved more frequently with the fluoroscopically guided semi-flexed anterior–posterior protocol than with the nonfluoroscopic fixed flexion or metatarso-phalangeal protocol.
- 6 Peterfy C, Kothari M. Imaging osteoarthritis: magnetic resonance imaging versus x-ray. Curr Rheumatol Rep 2006; 8:16–21.
 - 7 Gale DR, Chaisson CE, Totterman SM, *et al.* Meniscal subluxation: association with osteoarthritis and joint space narrowing. Osteoarthritis Cartilage 1999; 7:526–532.
 - 8 Adams JG, McAlindon T, Dimasi M, *et al.* Contribution of meniscal extrusion and cartilage loss to joint space narrowing in osteoarthritis. Clin Radiol 1999; 54:502–506.
 - 9 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.
- This study highlighted that the meniscus (both its position and degeneration) accounts for a substantial proportion of the variance in joint space width, and that the change in meniscal position accounts for a substantial proportion of change in JSN. This has important implications for trials testing osteoarthritis disease modifying treatments.
- 10 Peterfy C, Woodworth T, Altman R. Workshop for consensus on osteoarthritis imaging. Osteoarthritis Cartilage 2006; 14 (Suppl 1):1.
 - 11 Conaghan PG, Felson D, Gold G, *et al.* MRI and noncartilaginous structures in knee osteoarthritis. Osteoarthritis Cartilage 2006; 14 (Suppl 1):87–94.
- This review provides a comprehensive summary on current MRI methods for identifying and quantifying noncartilaginous structures and summarizes their associations with both osteoarthritis symptoms and structural progression of osteoarthritis.
- 12 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.
 - 13 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.
 - 14 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.
 - 15 Conaghan PG, Hunter D, Tennant A, *et al.* Evaluation an MRI scoring system for osteoarthritis of the knee using modern psychometric approaches [abstract]. Osteoarthritis Cartilage 2004; 12 (Suppl B):S118.
 - 16 Peterfy CG, Gold G, Eckstein F, *et al.* MRI protocols for whole-organ assessment of the knee in osteoarthritis. Osteoarthritis Cartilage 2006; 14 (Suppl 1):95–111.
- This study summarized MRI protocol and sequence considerations for whole organ assessment in knee osteoarthritis.

- 17 Ben Galim P, Steinberg EL, Amir H, *et al.* Accuracy of magnetic resonance imaging of the knee and unjustified surgery. *Clin Orthop Relat Res* 2006; 447:100–104.
- This study highlighted that MRI assessment of joint integrity has only limited accuracy when not being performed in expert centers.
- 18 Conaghan PG, Tennant A, Peterfy CG, *et al.* Examining a whole-organ magnetic resonance imaging scoring system for osteoarthritis of the knee using Rasch analysis. *Osteoarthritis Cartilage* 2006; 14 (Suppl 1): 116–121.
- This study employed RASCH analysis of the WOMBS instrument and demonstrated that a substantial proportion of subjects in the study populations evaluated had zero scores in several of the WOMBS subscales. Few of the subscales met the requirements of the RASCH measurement model when summed across all sites, and summations of some postulated compartmentally based sites also failed to fit the RASCH model. This limits the validity of the subscales generated.
- 19 Felson DT, Chaisson CE, Hill CL, *et al.* The association of bone marrow lesions with pain in knee osteoarthritis. *Ann Intern Med* 2001; 134:541–549.
- 20 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.
- 21 Link TM, Steinbach LS, Ghosh S, *et al.* Osteoarthritis: MR imaging findings in different stages of disease and correlation with clinical findings. *Radiology* 2003; 226:373–381.
- 22 Kornaat PR, Bloem JL, Ceulemans RY, *et al.* Osteoarthritis of the knee: association between clinical features and MR imaging findings. *Radiology* 2006; 239:811–817.
- This study in 205 patients with symptomatic osteoarthritis reported that large joint effusion was associated with pain (OR, 9.99) and stiffness (OR, 4.67), and the presence of patellofemoral osteophytes with pain (OR, 2.25), but that other imaging findings, including focal or diffuse cartilaginous abnormalities, subchondral cysts, bone marrow edema, subluxation of the meniscus, meniscal tears, or Baker cysts, were not associated with symptoms.
- 23 Torres L, Dunlop DD, Peterfy C, *et al.* The relationship between specific tissue lesions and pain severity in persons with knee osteoarthritis. *Osteoarthritis Cartilage* 2006; 14:1033–1040.
- This study in 143 patients with primary (idiopathic) knee osteoarthritis and definite tibiofemoral osteophytes reports a significant increase in median pain for bone attrition, bone marrow lesions, meniscal tears, and grade 2 or 3 synovitis/effusion, borderline significance for osteophytes and cartilage status, and no significance for bone cysts or meniscal subluxation.
- 24 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.
- This study in 264 patients highlighted the importance of an intact and functioning meniscus in subjects with symptomatic knee osteoarthritis, in that loss of this function has important consequences for cartilage loss.
- 25 Hunter DJ, Zhang Y, Niu J, *et al.* Increase in bone marrow lesions associated with cartilage loss: a longitudinal magnetic resonance imaging study of knee osteoarthritis. *Arthritis Rheum* 2006; 54:1529–1535.
- This study in 217 subjects highlighted that bone marrow lesions are unlikely to resolve and often get larger over time. Compared to BMLs that stay the same, enlarging BMLs are strongly associated with more rapid cartilage loss. Furthermore, change in BML is mediated by limb alignment.
- 26 Hunter DJ, Conaghan PG, Peterfy CG, *et al.* Responsiveness, effect size, and smallest detectable difference of Magnetic Resonance Imaging in knee osteoarthritis. *Osteoarthritis Cartilage* 2006; 14 (Suppl 1):112–115.
- This study in 150 subjects identified that MRI measures of cartilage morphology, synovitis and osteophytes appeared to be more responsive to change than other measures, albeit all the effect sizes and standardized response means were small.
- 27 Gold GE, Burstein D, Dardzinski B, *et al.* MRI of articular cartilage in OA: novel pulse sequences and compositional/functional markers. *Osteoarthritis Cartilage* 2006; 14 (Suppl 1):76–86.
- 28 Eckstein F, Cicuttini F, Raynauld JP, *et al.* Magnetic resonance imaging (MRI) of articular cartilage in knee osteoarthritis (OA): morphological assessment. *Osteoarthritis Cartilage* 2006; 14 (Suppl 1):46–75.
- This review provides a comprehensive summary of current MRI and image analysis methods for quantifying articular cartilage morphology (volume, thickness and others) and reviews validation and test-retest studies. The review also provides a meta-analysis of longitudinal studies published to date.
- 29 Gold GE, Reeder SB, Yu H, *et al.* Articular cartilage of the knee: rapid three-dimensional MR imaging at 3.0 T with IDEAL balanced steady-state free precession—initial experience. *Radiology* 2006; 240:546–551.
- 30 Pakin SK, Cavalcanti C, La Rocca R, *et al.* Ultra-high-field MRI of knee joint at 7.0T: preliminary experience. *Acad Radiol* 2006; 13:1135–1142.
- This study was the first to describe diarthrodial joint imaging at 7 Tesla.
- 31 Eckstein F, Charles HC, Buck RJ, *et al.* Accuracy and precision of quantitative assessment of cartilage morphology by magnetic resonance imaging at 3.0T. *Arthritis Rheum* 2005; 52:3132–3136.
- 32 Eckstein F, Hudelmaier M, Wirth W, *et al.* Double echo steady state magnetic resonance imaging of knee articular cartilage at 3 Tesla: a pilot study for the Osteoarthritis Initiative. *Ann Rheum Dis* 2006; 65:433–441.
- This is the first publication from the Osteoarthritis Initiative (OAI) pilot study and compares the test–retest precision of a double echo steady state MR sequence with water excitation used in the OAI with that of the previously validated FLASHwe sequence. The study reports similar reproducibility and quantitative agreement of the two protocols.
- 33 Kornaat PR, Koo S, Andriacchi TP, *et al.* Comparison of quantitative cartilage measurements acquired on two 3.0T MRI systems from different manufacturers. *J Magn Reson Imaging* 2006; 23:770–773.
- 34 Inglis D, Pui M, Ioannidis G, *et al.* Accuracy and test-retest precision of quantitative cartilage morphology on a 1.0 T peripheral magnetic resonance imaging system. *Osteoarthritis Cartilage* 2007; 15:110–115.
- 35 Eisenhart-Rothe R, Graichen H, Hudelmaier M, *et al.* Femorotibial and patellar cartilage loss in patients prior to total knee arthroplasty, heterogeneity, and correlation with alignment of the knee. *Ann Rheum Dis* 2006; 65:69–73.
- 36 Otterness IG, Eckstein F. Women have thinner cartilage and smaller joint surfaces than men after adjustment for body height and weight. *Osteoarthritis Cartilage* 2007 Feb 21; [Epub ahead of print].
- 37 Wang Y, Ding C, Wluka AE, *et al.* Factors affecting progression of knee cartilage defects in normal subjects over 2 years. *Rheumatology (Oxford)* 2006; 45:79–84.
- 38 Eckstein F, Ateshian G, Burgkart R, *et al.* Proposal for a nomenclature for magnetic resonance imaging based measures of articular cartilage in osteoarthritis. *Osteoarthritis Cartilage* 2006; 14:974–983.
- This proposal by an international group of experts presents a nomenclature for definitions and names to be used in scientific communications on MRI measurement of cartilage morphology or composition and gives recommendations as to which minimal methodological information should be provided when reporting MRI-based measures of articular cartilage in osteoarthritis.
- 39 Mosher TJ, Pruett SW. Magnetic resonance imaging of superficial cartilage lesions: role of contrast in lesion detection. *J Magn Reson Imaging* 1999; 10:178–182.
- 40 Eckstein F, Heudorfer L, Faber SC, *et al.* Long-term and resegmentation precision of quantitative cartilage MR imaging (qMRI). *Osteoarthritis Cartilage* 2002; 10:922–928.
- 41 Eckstein F, Kunz M, Hudelmaier M, *et al.* Impact of coil design on the contrast-to-noise ratio, precision, and consistency of quantitative cartilage morphology at 3 Tesla: a pilot study for the osteoarthritis initiative. *Magn Reson Med* 2007; 57:448–454.
- This describes the first study to apply phase array coils in quantitative cartilage imaging, derived from Osteoarthritis Initiative pilot data. The study reported no increased precision of cartilage morphometry with phased array coils, despite higher contrast-to-noise ratios for cartilage tissue.
- 42 Gandy SJ, Dieppe PA, Keen MC, *et al.* No loss of cartilage volume over three years in patients with knee osteoarthritis as assessed by magnetic resonance imaging. *Osteoarthritis Cartilage* 2002; 10:929–937.
- 43 Cicuttini FM, Wluka AE, Wang Y, *et al.* Longitudinal study of changes in tibial and femoral cartilage in knee osteoarthritis. *Arthritis Rheum* 2004; 50: 94–97.
- 44 Wluka AE, Stuckey S, Snaddon J, *et al.* The determinants of change in tibial cartilage volume in osteoarthritic knees. *Arthritis Rheum* 2002; 46:2065–2072.
- 45 Wluka AE, Forbes A, Wang Y, *et al.* Knee cartilage loss in symptomatic knee osteoarthritis over 4.5 years. *Arthritis Res Ther* 2006; 8:R90.
- This study described cartilage volume loss in a cohort 78 subjects over a period of 2 and 4.5 years, respectively. The annual percentage losses (over 4.5 years) were $3.7 \pm 4.7\%$ (mean \pm SD) in the medial tibia and $4.4 \pm 44.7\%$ in the lateral tibia. Cartilage volume in each individual seemed to track over the study period relative to other study participants.
- 46 Raynauld JP, Martel-Pelletier J, Berthiaume MJ, *et al.* Quantitative magnetic resonance imaging evaluation of knee osteoarthritis progression over 2 years and correlation with clinical symptoms and radiologic changes. *Arthritis Rheum* 2004; 50:476–487.
- 47 Berthiaume MJ, Raynauld JP, Martel-Pelletier J, *et al.* Meniscal tear and extrusion are strongly associated with progression of symptomatic knee osteoarthritis as assessed by quantitative magnetic resonance imaging. *Ann Rheum Dis* 2005; 64:556–563.

- 48 Raynauld JP, Martel-Pelletier J, Berthiaume MJ, *et al.* Long term evaluation of disease progression through the quantitative magnetic resonance imaging of symptomatic knee osteoarthritis patients: correlation with clinical symptoms and radiographic changes. *Arthritis Res Ther* 2006; 8:R21.
- This study has described cartilage volume loss over 12 and 24 months, respectively, and its association with symptoms, radiographic change, and risk factors of osteoarthritis in 107 patients. Medial femorotibial cartilage volume loss was $-5.5 \pm 4.3\%$ at 12 months and $-8.3 \pm 6.5\%$ at 24 months. The predictors of fast cartilage loss were the presence of severe meniscal extrusion ($P=0.001$), severe medial tear ($P=0.005$), medial or lateral bone marrow lesions ($P=0.03$), high BMI ($P<0.05$), weight ($P<0.05$) and age ($P<0.05$). No association was found between cartilage volume change and clinical outcome (WOMAC score), joint space narrowing in radiographs, or urine biomarker levels.
- 49 Eckstein F, Burstein D, Link TM. Quantitative MRI of cartilage and bone: degenerative changes in osteoarthritis. *NMR Biomed* 2006; 19:822–854. This review provides a comprehensive summary on current methodology for semiquantitative whole organ evaluation of joints, quantifying articular cartilage morphology and composition and bone changes in osteoarthritis.
- 50 Bruyere O, Genant H, Kothari M, *et al.* Longitudinal study of magnetic resonance imaging and standard X-rays to assess disease progression in osteoarthritis. *Osteoarthritis Cartilage* 2007; 15:98–103.
- This study compares 1-year changes in radiographs, WOMS scores and cartilage volume in 62 osteoarthritis patients. Medial femoro-tibial joint space width decreased by $6.7 \pm 20.5\%$, medial cartilage volume by $0.4 \pm 16.7\%$ and medial cartilage thickness by $2.1 \pm 11.3\%$. Medial femoro-tibial JSN was weekly correlated with loss of medial tibial cartilage volume ($r=0.25$, $P<0.05$), loss of medial tibial cartilage thickness ($r=0.28$, $P<0.05$) and progression of the WOMS score ($r=-0.35$, $P<0.01$). The MR sequence used for assessment of cartilage volume, however, had inferior resolution (3 mm slice thickness, 0.6 mm in-plane resolution) to those commonly used for quantitative cartilage imaging (1.5 mm slice thickness, 0.3 mm in-plane resolution).
- 51 Cicuttini F, Hankin J, Jones G, *et al.* Comparison of conventional standing knee radiographs and magnetic resonance imaging in assessing progression of tibiofemoral joint osteoarthritis. *Osteoarthritis Cartilage* 2005; 13:722–727.
- 52 Romeder F, Eckstein F, Hudelmaier M, *et al.* Longitudinal change or articular cartilage morphology as a function of varus and valgus malalignment in knee osteoarthritis [abstract]. *Osteoarthritis Cart* 2006; 14 (Suppl B):S136.
- 53 Zhai G, Ding C, Cicuttini F, *et al.* A longitudinal study of the association between knee alignment and change in cartilage volume and chondral defects in a largely nonosteoarthritic population. *J Rheumatol* 2007; 34: 181–186.
- 54 Koo S, Gold GE, Andriacchi TP. Considerations in measuring cartilage thickness using MRI: factors influencing reproducibility and accuracy. *Osteoarthritis Cartilage* 2005; 13:782–789.
- 55 Raynauld J-P, Pelletier JM, Berthiaume M-J, *et al.* The loss of cartilage volume/thickness on the weight bearing areas in knee osteoarthritis patients, assessed by quantitative MRI, is correlated with severity of symptoms and worsening of pain over time [abstract]. *Osteoarthritis Cart* 2006; 14 (Suppl B):S26.
- 56 Wirth W, Roth M, Kraus V, *et al.* Regional analysis of cartilage morphology in defined anatomical subregions of femorotibial cartilages [abstract]. *Osteoarthritis Cart* 2006; 14 (Suppl. B):S137.
- 57 Phan CM, Link TM, Blumenkrantz G, *et al.* MR imaging findings in the follow-up of patients with different stages of knee osteoarthritis and the correlation with clinical symptoms. *Eur Radiol* 2006; 16:608–618.
- 58 Hunter DJ, March L, Sambrook PN. The association of cartilage volume with knee pain. *Osteoarthritis Cartilage* 2003; 11:725–729.
- 59 Wluka AE, Wolfe R, Stuckey S, *et al.* How does tibial cartilage volume relate to symptoms in subjects with knee osteoarthritis? *Ann Rheum Dis* 2004; 63:264–268.
- 60 Cicuttini FM, Jones G, Forbes A, *et al.* Rate of cartilage loss at two years predicts subsequent total knee arthroplasty: a prospective study. *Ann Rheum Dis* 2004; 63:1124–1127.
- 61 Link TM, Stahl R, Woertler K. Cartilage imaging: motivation, techniques, current and future significance. *Eur Radiol* 2007; 17:1135–1146.
- 62 Shindle MK, Foo LF, Kelly BT, *et al.* Magnetic resonance imaging of cartilage in the athlete: current techniques and spectrum of disease. *J Bone Joint Surg Am* 2006; 88A (Suppl 4):27–46.
- 63 Gold GE, Hargreaves BA, Stevens KJ, *et al.* Advanced magnetic resonance imaging of articular cartilage. *Orthop Clin North Am* 2006; 37:331–347.
- 64 Kneeland JB, Reddy R. Frontiers in musculoskeletal MRI: articular cartilage. *J Magn Reson Imaging* 2007; 25:339–344.
- 65 Mosher TJ, Dardzinski BJ. Cartilage MRI T2 relaxation time mapping: overview and applications. *Semin Musculoskelet Radiol* 2004; 8:355–368.
- 66 Burstein D, Gray ML. Is MRI fulfilling its promise for molecular imaging of cartilage in arthritis? *Osteoarthritis Cartilage* 2006; 14:1087–1090.
- 67 Glaser C, Mendlik T, Dinges J, *et al.* Global and regional reproducibility of T2 relaxation time measurements in human patellar cartilage. *Magn Reson Med* 2006; 56:527–534.
- This was one of the first studies to evaluate the reproducibility of in-vivo cartilage T2 mapping.
- 68 Lusse S, Claassen H, Gehrke T, *et al.* Evaluation of water content by spatially resolved transverse relaxation times of human articular cartilage. *Magn Reson Imaging* 2000; 18:423–430.
- 69 Menezes NM, Gray ML, Hartke JR, *et al.* T2 and T1rho MRI in articular cartilage systems. *Magn Reson Med* 2004; 51:503–509.
- 70 Nieminen MT, Rieppo J, Toyra J, *et al.* T2 relaxation reveals spatial collagen architecture in articular cartilage: a comparative quantitative MRI and polarized light microscopic study. *Magn Reson Med* 2001; 46:487–493.
- 71 Xia Y, Moody JB, Alhadlaq H. Orientational dependence of T2 relaxation in articular cartilage: A microscopic MRI (microMRI) study. *Magn Reson Med* 2002; 48:460–469.
- 72 Grunder W. MRI assessment of cartilage ultrastructure. *NMR Biomed* 2006; 19:855–876.
- 73 Nissi MJ, Rieppo J, Toyra J, *et al.* T(2) relaxation time mapping reveals age- and species-related diversity of collagen network architecture in articular cartilage. *Osteoarthritis Cartilage* 2006; 14:1265–1271.
- This study demonstrated sensitivity of cartilage T2 mapping to developmental changes in the cartilage collagen matrix.
- 74 Shinar H, Navon G. Multinuclear NMR and microscopic MRI studies of the articular cartilage nanostructure. *NMR Biomed* 2006; 19:877–893.
- 75 Goebel JC, Watrin-Pinzano A, Bettembourg-Brault I, *et al.* Age-related quantitative MRI changes in healthy cartilage: preliminary results. *Biorheology* 2006; 43:547–551.
- 76 Mosher TJ, Dardzinski BJ, Smith MB. Human articular cartilage: influence of aging and early symptomatic degeneration on the spatial variation of T2—preliminary findings at 3 T. *Radiology* 2000; 214:259–266.
- 77 Mosher TJ, Liu Y, Yang QX, *et al.* Age dependency of cartilage magnetic resonance imaging T2 relaxation times in asymptomatic women. *Arthritis Rheum* 2004; 50:2820–2828.
- 78 Dunn TC, Lu Y, Jin H, *et al.* T2 relaxation time of cartilage at MR imaging: comparison with severity of knee osteoarthritis. *Radiology* 2004; 232:592–598.
- 79 Li X, Benjamin MC, Link TM, *et al.* In vivo T(1rho) and T(2) mapping of articular cartilage in osteoarthritis of the knee using 3T MRI. *Osteoarthritis Cartilage* 2007; Feb 15 [Epub ahead of print].
- 80 Li X, Han ET, Ma CB, *et al.* In vivo 3T spiral imaging based multislice T(1rho) mapping of knee cartilage in osteoarthritis. *Magn Reson Med* 2005; 54: 929–936.
- 81 Koff MF, Amrami KK, Kaufman KR. Clinical evaluation of T2 values of patellar cartilage in patients with osteoarthritis. *Osteoarthritis Cartilage* 2007; 15:198–204.
- 82 Bashir A, Gray ML, Boutin RD, *et al.* Glycosaminoglycan in articular cartilage: in vivo assessment with delayed Gd(DTPA)(2-)-enhanced MR imaging. *Radiology* 1997; 205:551–558.
- 83 Burstein D, Velyvis J, Scott KT, *et al.* Protocol issues for delayed Gd(DTPA)(2-)-enhanced MRI (dGEMRIC) for clinical evaluation of articular cartilage. *Magn Reson Med* 2001; 45:36–41.
- 84 Tiderius C, Hori M, Williams A, *et al.* dGEMRIC as a function of BMI. *Osteoarthritis Cartilage* 2006; 14:1091–1097.
- 85 McKenzie CA, Williams A, Prasad PV, *et al.* Three-dimensional delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) at 1.5T and 3.0T. *J Magn Reson Imaging* 2006; 24:928–933.
- 86 Kimelman T, Vu A, Storey P, *et al.* Three-dimensional T1 mapping for dGEMRIC at 3.0 T using the Look Locker method. *Invest Radiol* 2006; 41:198–203.
- 87 Boesen M, Jensen KE, Qvistgaard E, *et al.* Delayed gadolinium-enhanced magnetic resonance imaging (dGEMRIC) of hip joint cartilage: better cartilage delineation after intra-articular than intravenous gadolinium injection. *Acta Radiol* 2006; 47:391–396.
- 88 Nojiri T, Watanabe N, Namura T, *et al.* Utility of delayed gadolinium-enhanced MRI (dGEMRIC) for qualitative evaluation of articular cartilage of patellofemoral joint. *Knee Surg Sports Traumatol Arthrosc* 2006; 14:718–723.
- 89 Cunningham T, Jessel R, Zurakowski D, *et al.* Delayed gadolinium-enhanced magnetic resonance imaging of cartilage to predict early failure of Bernese periacetabular osteotomy for hip dysplasia. *J Bone Joint Surg Am* 2006; 88:1540–1548.
- This study reports on 47 patients undergoing a Bernese periacetabular osteotomy for the treatment of hip dysplasia. It shows that a low dGEMRIC score preoperatively is a strong predictor of a poor clinical outcome.

- 90** Lammentausta E, Kiviranta P, Nissi MJ, *et al.* T2 relaxation time and delayed gadolinium-enhanced MRI of cartilage (dGEMRIC) of human patellar cartilage at 1.5 T and 9.4 T: Relationships with tissue mechanical properties. *J Orthop Res* 2006; 24:366–374.
- 91** Vasara AI, Nieminen MT, Jurvelin JS, *et al.* Indentation stiffness of repair tissue after autologous chondrocyte transplantation. *Clin Orthop Relat Res* 2005; 233–242.
- 92** Trattnig S, Millington SA, Szomolanyi P, *et al.* MR imaging of osteochondral grafts and autologous chondrocyte implantation. *Eur Radiol* 2007; 17:103–118.
- 93** Kangarlu A, Gahunia HK. Magnetic resonance imaging characterization of osteochondral defect repair in a goat model at 8 T. *Osteoarthritis Cartilage* 2006; 14:52–62.
- 94** Potter HG, Foo LF. Magnetic resonance imaging of articular cartilage: trauma, degeneration, and repair. *Am J Sports Med* 2006; 34:661–677.
- 95** Kurkijarvi JE, Mattila L, Ojala RO, *et al.* Evaluation of cartilage repair in the distal femur after autologous chondrocyte transplantation using T2 relaxation time and dGEMRIC. *Osteoarthritis Cartilage* 2007; 15:372–378.
- This was one of the first studies comparing biomechanical properties of cartilage repair tissue following autologous chondrocyte implantation with dGEMRIC scores and T2 mapping. Combining these two quantitative magnetic resonance imaging techniques enables a more comprehensive characterization of cartilage repair than using dGEMRIC values alone [91].
- 96** White LM, Sussman MS, Hurtig M, *et al.* Cartilage T2 assessment: differentiation of normal hyaline cartilage and reparative tissue after arthroscopic cartilage repair in equine subjects. *Radiology* 2006; 241:407–414.
- In this study, cartilage T2 mapping was performed on 10 equine knees that had undergone osteochondral autograft transplantation (OAT) and microfracture arthroplasty (MFX) 12–24 months prior to the MRI. The spatial distribution of cartilage T2 and subjective assessment of cartilage T2 spatial distribution was compared with histologic results and collagen organization assessed at polarized light microscopy. A normal spatial variation in cartilage T2 was correlated with hyaline cartilage in OAT graft sites, while heterogeneously elevated T2 was observed in microfracture and OAT harvest sites demonstrating fibrous repair tissue. The study is important because it provides evidence that T2 mapping is sensitive to repair tissue histology and may have the potential to differentiate hyaline from fibrocartilage repair tissue.
- 97** Borthakur A, Mellon E, Niyogi S, *et al.* Sodium and T1rho MRI for molecular and diagnostic imaging of articular cartilage. *NMR Biomed* 2006; 19:781–821.
- 98** Pakin SK, Xu J, Schweitzer ME, *et al.* Rapid 3D-T1rho mapping of the knee joint at 3.0T with parallel imaging. *Magn Reson Med* 2006; 56:563–571.
- This technical paper describes modifications of a 3D gradient echo T1rho mapping technique at 3T that leads to decreased acquisition time and lower specific absorption rate.
- 99** Pakin SK, Schweitzer ME, Regatte RR. 3D-T1rho quantitation of patellar cartilage at 3.0T. *J Magn Reson Imaging* 2006; 24:1357–1363.
- 100** Regatte RR, Akella SV, Lonner JH, *et al.* T1rho relaxation mapping in human osteoarthritis (OA) cartilage: comparison of T1rho with T2. *J Magn Reson Imaging* 2006; 23:547–553.
- This is an interesting preliminary study of osteochondral tissue samples from eight subjects undergoing total knee replacement and reports elevated T2 and T1rho values in osteoarthritic cartilage compared to healthy tissue. Compared to T2, T1rho demonstrated a larger dynamic range suggesting it may be more responsive than T2 to cartilage degradation.