A principal obstacle to the study of arthritis and the development of well-designed treatment protocols has been the lack of reliable clinical, laboratory or radiographic methods for monitoring disease progression and therapeutic response. Radiography has been the mainstay of imaging evaluation of arthritis. However, although refinements such as microfocal magnification, film digitization and computerized analysis have greatly advanced its capabilities [1, 2], radiography remains fundamentally limited in the type of information it can provide. Although it can detail osseous changes in patients with arthritis, radiography cannot directly examine the articular cartilage, synovial tissue and other important non-calcified structures in the joint. As such, it provides only a limited view of the complex disease process involved in arthritis.

The recent emergence of MRI as a technique of unprecedented power for examining internal derangements of the knee and other joints has fueled considerable interest in the prospect of using this modality as a tool to study arthritis and its treatments. In addition to offering true multiplanar versatility and high spatial resolution, MRI is uniquely capable of directly visualizing all components of the joint simultaneously. This includes the articular bones and bone marrow, the articular hyaline cartilage, the synovium and joint fluid, intra-articular ligaments, fat pads, menisci and labra, the joint capsule, and the periarticular muscles and tendons. Such a capability allows for the first time the joint to be examined as a whole organ, and arthritis to be viewed as a disease of organ failure.

In addition to delineating the anatomy, however, MRI is capable of quantifying a variety of compositional and functional parameters of articular tissues relevant to arthritis. Moreover, since MRI is a non-destructive technique, multiple parameters can be analyzed in the same region of tissue and frequent serial examinations can be performed on even asymptomatic patients.

Various MRI techniques can be used to examine the articular cartilage. Because of its fibrous nature, normal cartilage exhibits relatively rapid $T_2$ relaxation ($<20$ ms). Accordingly, $T_2$-weighted images depict this tissue as a low signal intensity structure with sharp delineation of its surface against the adjacent high signal intensity joint fluid. Recently developed magnetization-transfer sequences harness cross-relaxation between water and collagen in this tissue to generate additional contrast with the adjacent articular structures [3, 4]. Fat-suppressed, $T_1$-weighted sequences capitalize on the relatively short $T_1$ relaxation ($<700$ ms) of cartilage to generate tissue contrast [4–7]. Each of these latter two techniques can be combined with three-dimensional gradient echo imaging to include high in-plane and through-plane resolution (Fig. 1).

These techniques provide sufficient contrast and spatial resolution to conduct sophisticated three-dimensional analyses of the geometry of the cartilage [3–5]. In addition to shaded three-dimensional renderings of the tissue (Fig. 2), B-spline lines can be used to depict the surface topography and map contact areas between opposing articular surfaces [8] (Fig. 3). Such analyses could be used to study the role of abnormal articular tracking in the development and progression of arthritis, as well as to direct precise surgical repair of such disorders. Using relatively simple image-processing methods, it is possible to quantify the total volume of individual cartilage plates in the knees [4] and metacarpophalangeal joints [5] with ~95% reproducibility and accuracy. Changes of as little as 10–15% of the total volume of cartilage may be measurable with this method. More recently, it has become feasible to monitor regional changes in cartilage content using methods that map the cartilage thickness.

Even before any morphological changes become apparent, however, areas of matrix loss and increased water within diseased cartilage can be seen with MRI. These changes are most sensitively detected by $T_2$-weighted imaging as high signal intensity foci within the normally low signal intensity cartilage. Measuring changes in cartilage proton density, $T_1$ and $T_2$ with MRI probes the very earliest stages of cartilage degeneration, and may provide a sensitive tool for monitoring patients at risk for osteoarthritis. Other compositional and functional parameters of articular cartilage integrity, such as water diffusivity, proteoglycan content, collagen content and compressive stiffness, may also be measurable with MRI in the near future.

MRI is also capable of providing detailed information about the severity of synovial inflammation. Both magnetization transfer contrast and fat-suppressed, $T_1$-weighted gradient-echo can be used to delineate synovial morphology in vivo [3]. Intravenously administered gadolinium chelate (Gd-DTPA) rapidly enhances hypervascular synovial tissue and increases its $T_1$ contrast. Since Gd-DTPA diffuses freely into
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Fig. 1.—Fat-suppressed sagittal T1-weighted three-dimensional spoiled gradient-echo (40° flip angle, 58 ms TEs, 6 ms TEs) image of a knee depicts the articular cartilage as a high signal intensity band adjacent to low signal intensity synovial fluid and subchondral bone. By summing the total number of voxels within the image, the exact volume of each cartilage plate can be quantified with ~95% accuracy and reproducibility.

Fig. 2.—Shaded three-dimensional rendering of the patellar, femoral and tibial articular cartilages (posterolateral vantage point) generated from fat-suppressed T1-weighted gradient-echo images of the knee.

Fig. 3.—Map of in situ contact areas in the patellofemoral joint. MR images were segmented manually, and geometric models of the articular surfaces of the patellofemoral joint were generated from the contour curves using parametric bicubic B-spline representations. Contact areas between the B-spline geometric models were determined by the proximity method [10] and depicted in intervals of 0.5 mm. (From Ateshian, G.A., Cohen, Z.A., Kwak, S.D., Wang, V., Kelkar, R., Raimondo, R., Feldman, F., Miller, T.R., Mun, I.K., Bigliani, L.U., Mow, V.C., Peterfy, C.G. Determination of in situ contact areas in diarthroidal joints by MRI. International Mechanical Engineering Congress and Exposition, San Francisco, 1995.)
adjacent synovial fluid, however, its utility for delineating synovial anatomy is limited. This contrast agent can, nevertheless, be used to grade the severity of synovial inflammation in patients with arthritis, as the rate of synovial enhancement with Gd-DTPA correlates with histological appearance of this tissue [9].

Additionally, MRI provides useful information about the integrity of intra-articular ligaments and menisci, the appearance of the articular bones, and the status of periarticular muscles and tendons.

The majority of these technical capabilities are now widely available. Clinical MRI systems found at most major hospitals around the world can perform extremely sophisticated examinations, making multi-institutional and even multinational investigations feasible. Finally, as with other maturing technologies, the cost of MRI is continuously decreasing. This, along with additional clinical, histological and biochemical correlation of the changes seen on MRI, will further facilitate the acceptance of this technology as a tool of unprecedented and unparalleled power for monitoring arthritis and its treatment.

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