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MR Imaging Assessment of Articular Cartilage Repair Procedures

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Articular cartilage injury poses a serious problem for orthopedic surgeons. The associated pain and physical disability can have career-ending consequences in athletes and can restrict the ability to perform activities of daily living in any individual. In two separate studies, consisting of 31,156 and 1000 patients undergoing knee arthroscopy, cartilage lesions were found in greater than 60% of all patients, and approximately 5% of these lesions were classified as deep partial-thickness or full-thickness defects in patients less than 40 years of age.^{1,2}

Because articular cartilage is avascular, the transport of inflammatory mediators and cells to the site of tissue injury is limited; thus, cartilage has no intrinsic capacity to heal itself.^{3,4} Over the past two decades, there have been many exciting developments in the field of articular cartilage restoration. Patients who were previously offered only symptomatic relief now have a variety of treatment options, including microfracture, osteochondral autografting and allografting, restoration with resorbable synthetic scaffolds, and autologous chondrocyte implantation (ACI) (including matrix-assisted ACI [MACI]). This article reviews the different types of cartilage repair procedures and discusses their assessment using imaging.

BRIEF OVERVIEW OF MR IMAGING OF CARTILAGE

Many MR imaging sequences are currently used to evaluate cartilage morphology.⁵ Typical sequences include fat-suppressed, 3-D, gradientecho techniques^{6,7} and fast spin-echo techniques with and without fat suppression.^{8,9} These sequences have been extensively used to evaluate articular cartilage and have reported sensitivities and specificities for the detection of cartilage lesions close to or greater than 90% in some studies.

There has also been great interest recently in the use of MR imaging techniques to evaluate the biochemical composition of the cartilage matrix. These techniques include T2 mapping, delayed gadolinium-enhanced MR imaging of cartilage (dGEMRIC), T1rho mapping, and sodium MR imaging. T2 mapping reflects cartilage collagen content and hydration status,¹⁰ whereas dGEMRIC, T1rho mapping, and sodium MR imaging are all markers of cartilage proteoglycan content.^{5,11–13} Although these biochemical imaging techniques are less widely available, they may provide useful additional information regarding the status of the cartilage repair procedure.

Finally, with the development of ultra-high-field MR imaging scanners (7 T and above), there is the potential to improve on scanning techniques performed at standard clinical field strength (1.5 to 3 T).^{14–16} Because of the greater intrinsic signal-to-noise ratio available at ultra-high field (signal-to-noise ratio scales approximately with the magnitude of the magnetic field), images can be obtained with increased spatial resolution or decreased scan time. Ultra-high field also facilitates the performance of biochemical imaging techniques, such as sodium MR imaging, which is limited by low signal-to-noise ratio at standard clinical field strength.

PARAMETERS ASSESSED IN MR IMAGING OF CARTILAGE REPAIR

Multiple parameters should be assessed in MR imaging examinations of cartilage repair. In one study of patients who underwent either microfracture or ACI, the following MR imaging parameters were evaluated: signal intensity relative to native cartilage; morphology with respect to native cartilage (flush, proud, or depressed); delamination (in the setting of ACI); nature of the interface with the adjacent surface (presence or absence and size of fissures); degree of defect filling; integrity of cartilage on the opposite articular surface; and bony hypertrophy.¹⁷

Another group has proposed a formal grading system for MR imaging assessment of cartilage repair, magnetic resonance observation of cartilage repair (MOCART).¹⁸ Using fat-suppressed, 3-D, gradient-recalled echo, and fast spin-echo sequences, the investigators propose assessment of the following MR imaging parameters: degree of defect filling, integration to border zone, surface of repair tissue, structure of repair tissue, signal intensity of repair tissue, subchondral lamina, subchondral bone, adhesions, and synovitis. This scoring system was later validated in a 2-year longitudinal study of patients with matrix-assisted chondrocyte implantation,¹⁹ with certain parameters, such as degree of defect filling, structure of repair tissue, change in subchondral bone, and signal intensity of repair tissue, correlating well with clinical scores.

TYPES OF CARTILAGE REPAIR PROCEDURES AND APPEARANCE ON MR IMAGING

Microfracture

Rationale—Microfracture was introduced by Steadman and colleagues²⁰ in the early 1980s and was described as a treatment for full-thickness posttraumatic cartilage defects. As opposed to other marrow stimulation techniques, such as drilling, there is essentially no risk for thermal necrosis of surrounding tissue.²⁰ Through micropenetration of the subchondral bone plate, the cartilage defect is populated with platelets, growth factors, and bone marrow-derived mesenchymal stem cells, which mediate a fibrocartilaginous repair process. Fibrocartilage that forms within the defect is less well organized than normal hyaline articular cartilage and has a higher proportion of type I collagen; as a result, its biomechanical properties are inferior to that of hyaline cartilage.^{3,21,22}

Indications—Microfracture is a simple, single-stage procedure with relatively low patient morbidity. Microfracture is indicated as a first-line treatment for patients with small full-thickness cartilage defects in either the weight-bearing region of the femorotibial compartment or in an area of contact between the patella and trochlea. Unstable cartilage flaps are another indication for microfracture.^{23–25}

Surgical technique—An arthroscopic awl is used to make multiple holes or microfractures in the exposed subchondral bone plate. When fat droplets are seen coming from the marrow cavity, the appropriate depth of 2 to 4 mm has been reached. Significant functional improvement after microfracture has been documented at a minimum follow-up period of 2 years with the best results observed with good fill grade, low body mass index, and a short duration of preoperative symptoms.²⁶ The success of the procedure in athletes who perform high-impact sports is associated with lesion size less than 200 mm², preoperative symptoms less than 12 months, and no prior surgical intervention.²⁷ Although weight bearing is detrimental in the first 8 weeks after surgery, continuous passive motion is a critical component of rehabilitation that may help stimulate chondocyte matrix production and remodel the repair cartilage surface so that it is congruent with the native hyaline cartilage.^{28,29}

Imaging studies—The MR imaging appearance of reparative fibrocartilage after microfracture varies depending on the time after surgery. In general, the reparative fibrocartilage is hypertintense relative to native hyaline cartilage (Figs. 1 and 2). Adverse functional scores after 24 months have been correlated with poor percentage of fill by repair tissue and incomplete peripheral integration.²⁶ Lack of peripheral integration and thinning of the repair tissue may increase mechanical stress on the reparative fibrocartilage, leading to early cartilage degeneration and functional decline.

Two studies have used T2 mapping to evaluate the status of reparative fibrocartilage induced by microfracture. In both studies, fibrocartilage did not demonstrate the characteristic spatial variation in T2 values that is seen with native hyaline cartilage (higher T2 values near the articular surface and lower T2 values near subchondral bone).^{30,31} In addition, the overall global T2 value was lower for fibrocartilage repair tissue than for native hyaline cartilage.³¹

Fibrocartilage formed after microfracture has also been evaluated using dGEMRIC. In one study, fibrocartilage demonstrated a greater difference between precontrast and postcontrast T1 relaxation time compared with repair tissue formed after MACI³²; this suggests a lower glycosaminoglycan content in fibrocartilage compared with other types of cartilage repair tissue.³²

Osteochondral Autograft Transfer

Rationale—The use of osteochondral autografts was first described by Yamashita and coworkers³³ and later popularized by Bobi³⁴ (single plugs) and Hangody and colleagues^{35,36} (multiple plugs or mosaicplasty). This technique involves repairing a cartilage defect with one or more small cylindrical osteochondral plugs harvested from a relatively non-weight-bearing portion of the patellofemoral joint or from the margin of the intercondylar notch. Histologic evaluations after osteochondral autograft transfer in animal models reveal consistent survival of transplanted hyaline cartilage, deep matrix integration and formation of a composite layer with native surrounding cartilage, ingrowth of fibrocartilage at the osseous base of the defect, and osseous incorporation of the graft with recipient subchondral bone.^{36–38}

Indications—The main indications for osteochondral autograft transfer are focal cartilage defects measuring 1 to 5 cm², typically due to trauma or osteochondritis dissecans. Under unusual circumstances, defects as large as 8 to 9 cm² have been repaired, but for lesions of this size, there is limited donor tissue available.³⁶ Fifty years is the recommended upper age limit for the procedure. Although osteochondral autografting was initially performed only on the weight-bearing surfaces of the femoral condyles and patellofemoral joints, it can also be used to treat cartilage defects of the talus, tibia, humeral capitellum, and femoral head.

Surgical technique—Osteochondral autografting can be performed arthroscopically or via an open arthrotomy. Patients are informed preoperatively of the potential need to harvest plugs from the contralateral knee, especially when treating larger cartilage defects. After gaining surgical access, the size of the cartilage lesion is assessed, and the number, diameter, and position of graft plugs required to fill the defect are determined. Femoral condylar lesions are filled with plugs from the margins of the medial and lateral femoral condyles above the sulcus terminalis, whereas lesions in the trochlear groove are treated with plugs harvested from the intercondylar notch.^{39–41}

Osteochondral autografting requires 2 weeks of non-weight-bearing during the immediate postoperative period followed by 2 weeks of partial weight bearing. Successful clinical outcomes have been reported by many groups. In a 10-year follow-up study of 831 patients, good to excellent results were reported in 92%, 87%, and 79% of femoral condylar, tibial, and patellofemoral implantations, respectively.³⁶ In one clinical trial comparing osteochondral autografting with ACI, osteochondral autografting was associated with faster recovery at 6, 12, and 24 months, although both procedures resulted in decreased symptoms at 24 months.⁴²

Imaging studies—On MR imaging, the position of the osteochondral plug within the recipient site should be evaluated, and there should be no graft migration. Perigraft edema can be found in greater than 50% of patients at 1 year, and this gradually decreases by 3 years (Figs. 3 and 4).⁴³ The presence of subchondral cysts or persistent extensive perigraft edema at 3 years may reflect poor osseous incorporation.^{43,44} Rarely, osteonecrosis has been reported as a complication of osteochondral autografting.⁴³ The thickness and congruity of the articular surface should also be evaluated. Ideally, the thickness of the repair cartilage should be similar to that of the surrounding native hyaline cartilage with a smooth, congruent articular surface (Fig. 5). The deep bone-bone interface may demonstrate an incongruent surface, because the osteochondral plug may have been harvested from a location with a differing cartilage thickness.

Osteochondral Allograft

Rationale—Osteochondral allografting involves the replacement of damaged articular cartilage with mature hyaline cartilage from a suitable donor. The advantages of osteochondral allografts over autografts are (1) the avoidance of morbidity from the autograft harvesting procedure, (2) the ability to repair larger defects because more donor tissue can be harvested, and (3) the ability to harvest tissue from a site matching the exact location of a patient's cartilage defect, which allows more accurate matching of the size and contour of the graft to the defect.⁴⁵

The rationale for this procedure is that the transplanted hyaline cartilage contains living chondrocytes that are capable of supporting the cartilage matrix within the host indefinitely.⁴⁶ The osteochondral allograft is considered immunoprivileged, because cartilage is avascular and chondrocytes are protected from host immune surveillance due to their location within the matrix.^{46,47} Donor cartilage is not matched to recipient HLA type

or blood type. Procurement and processing of donor tissue is, however, performed according to American Association of Tissue Banks guidelines,⁴⁸ which includes an extensive medical, social, and sexual history of the donor as well as serologic testing for HIV, hepatitis, syphilis, and other blood-borne pathogens. As a result, although fresh osteochondral allografts are necessary to ensure maximum chondrocyte survival, tissue is transplanted no sooner than 14 days and sometimes as late as 40 days after harvesting while tests for viral and bacterial contamination are conducted. Approximately 5 million fresh osteochondral allografts have been transplanted over the past decade, and few documented cases of disease transmission have been reported.⁴⁹

Indications—In the knee, osteochondral allografting has been used for multiple indications, including traumatic or degenerative cartilage lesions, osteochondritis dissecans, osteonecrosis, or salvage of a previous cartilage repair procedure. The size of the cartilage defect can be as large as 15 cm².⁵⁰ Osteochondral allografting has also been performed in the ankle and hip for similar indications and when other procedures, such as osteochondral autografting, are not feasible.

Surgical technique—Osteochondral allografting is performed through a mini arthrotomy or standard arthrotomy to expose the cartilage lesion.⁵¹ The remaining articular cartilage and damaged subchondral bone are removed. The allograft plug (10 to 35 mm in diameter) is then removed from the donor tissue using a coring reamer, and the graft is shaped to match the size and depth of the recipient lesion site. The graft is then gently inserted with a tamp or with joint compression during range of motion, with loose grafts fixed with bioabsorbable pins or screws. Eighty-five percent 10-year survivorship of allografts has been reported for posttraumatic defects of the femur.⁵² Multiple studies have documented 80% to 84% good to excellent results at 6-year follow-up in patients treated with osteochondral allografts for a variety of conditions.^{53,54}

Imaging studies—For osteochondral allografts, the same features should be evaluated on MR imaging as for osteochondral autografts (Fig. 6). In one animal study comparing osteochondral autografts with allografts, MR imaging revealed no statistically significant differences in the MR imaging appearance of autografts and allografts. The MR imaging features evaluated included graft cartilage signal intensity, appearance of the subchondral plate and articular surface (flush, depressed, proud, or displaced), interface with the adjacent cartilage (smooth, partial-thickness, or full-thickness offset), percentage fill of the defect by thirds, trabecular incorporation of the grafts (complete, partial, or poor), signal of bone graft (fat, edema, or fibrosis), and cartilage T2 relaxation times.⁴⁵ In 90% of subjects, the investigators noted a persistent cleft at the interface between the graft and host cartilage and concluded that hyaline cartilage cannot regenerate across a physical defect.

In another study involving 19 human subjects with symptomatic osteochondral lesions of the knee who were treated with hypothermically stored allografts, 2-year follow-up MR imaging examinations revealed normal graft cartilage thickness in 18 subjects, graft cartilage signal characteristics similar to native hyaline cartilage in 8 subjects, and complete or partial osseous incorporation of the allograft in 14 subjects.⁵⁰ The investigators concluded that hypothermically stored allografts are effective at short-term follow-up for treatment of symptomatic osteochondral lesions of the knee.

Finally, similar to osteochondral autografts, osteonecrosis within osteochondral allografts has been reported.⁵⁵

Repair with Synthetic Resorbable Scaffolds

Rationale—In recent years, there has also been great interest in repair of cartilage lesions using synthetic resorbable scaffolds.^{56–60} These scaffolds are small, cylindrical, porous plugs composed of biodegradable material (for example, a composite of polylactide-co-glycolide, calcium sulfate, and polyglycolide fibers in TruFit plugs from OsteoBiologics, San Antonio, TX, USA) that serve to facilitate the ingrowth of new healing tissue. They can be used alone or as delivery vehicles for cells and growth factors. The implants are biphasic or multiphasic in that the superficial layer has mechanical properties resembling that of hyaline cartilage and the deeper layer has mechanical properties resembling that of subchondral bone. In animal studies, the scaffolds are gradually resorbed and are replaced by hyaline cartilage and subchondral bone.⁵⁷

Indications—The indications for the use of synthetic resorbable scaffolds for cartilage repair are similar to those for osteochondral autografts and allografts. The cartilage repair procedure is considered a potential treatment option for patients less than 50 years of age who have focal cartilage defects measuring 1 to 5 cm² in size. The main advantage of using synthetic resorbable scaffolds for cartilage repair is the avoidance of the limitations and potential complications associated with osteochondral autografting and allografting techniques, such as the need for an initial surgical procedure to harvest donor tissue, the lack of available donor tissue, and the risk of infection from allograft tissue.

Surgical technique—In the first step of the procedure, an osteochondral coring drill is selected such that its diameter completely covers the cartilage lesion of interest. The drill is inserted into the subchondral bone to a depth of 5 to 15 mm, and osteochondral tissue is removed. Using a delivery device with a measuring tamp, the synthetic implant is cut to the appropriate size of the surgically created osteochondral defect. The delivery device is then used to manually deliver the implant into the osteochondral defect. If further contouring is needed, the measuring tamp can be used to impact the surface of the implant such that its surface is flush with that of surrounding native hyaline cartilage. No randomized controlled trials have been performed comparing this technique with other cartilage repair techniques, although preclinical studies and isolated reports suggest promising results.^{56–61}

Imaging studies—Similar to the evaluation of osteochondral autografts and allografts, MR imaging of resorbable scaffolds should include an assessment of joint surface congruity, lesion fill, and the amount of osseous incorporation. At 3 months, the implanted scaffold has typically not integrated with the surrounding subchondral bone, and the implant can be hyperintense in signal relative to adjacent native hyaline cartilage (Fig. 7). By 12 months, however, the plug should be integrated with surrounding subchondral bone, such that the borders of the plug are less visible and a layer of overlying hyaline cartilage is seen (Fig. 8).

Autologous Chondrocyte Implantation and Matrix-Assisted Autologous Chondrocyte Implantation

Rationale—In ACI, chondrocytes are harvested from a patient and then grown in tissue culture medium. The chondrocytes are then reimplanted within the patient's cartilage defect beneath a periosteal patch and produce new cartilage repair tissue. The success of ACI in human studies was initially described by Brittberg and colleagues in 1994.⁶²

Indications—ACI is indicated for near-full or full-thickness cartilage defects 2 cm² or greater in size. High-demand patients between the ages of 15 and 55 years with excellent treatment compliance are usually chosen. Although some surgeons believe the procedure should be reserved for patients who have failed another primary intervention, such as microfracture, others use it as a primary technique.⁵¹ Some surgeons also treat smaller

cartilage lesions less than 1 cm² in size with primary ACI.⁵¹ If subchondral bone is damaged to a depth greater than 6 to 8 mm, staged or concomitant bone grafting is undertaken.

Surgical technique—ACI requires two procedures.⁵¹ Initially, patients undergo diagnostic arthroscopy, and hyaline cartilage is harvested from a non-weight-bearing area of the knee, such as the superomedial trochlear ridge or lateral intercondylar notch. From this specimen, approximately 300,000 chondrocytes are isolated, which are grown in cell culture to produce approximately 10 million cells. In the second procedure, patients undergo arthrotomy and damaged cartilage is débrided without injuring subchondral bone. A periosteal patch is prepared (typically from the proximal medial tibial diaphysis distal to the pes anserinus insertion) and sutured over the defect, and the culture chondrocytes are injected under the periosteal patch. The patch is then sealed with additional suture and fibrin glue.

Potential complications with the use of a periosteal patch led to the development of collagen membranes to seal cartilage defects treated with ACI.⁶³ This led to the recognition that chondrocytes could be directly seeded onto a type I/III collagen membrane, which could then be delivered as a cell-scaffold construct for implantation. This procedure is currently referred to as matrix-assisted ACI (MACI). Other scaffolds have been developed and can be composed of carbohydrates (polylactic/polyglycolic acid, hyaluronan, agarose, alginate), protein polymers (fibrin or gelatin), and artificial polymers (carbon fiber, hydroxyapatite, polytetrafluoroethylene, polybutyric acid). MACI obviates a periosteal patch and greatly simplifies the overall procedure. In addition, the biomatrix seeded with chondrocytes has theoretic advantages of less chondrocyte leakage, more homogeneous chondrocyte distribution, and less graft hypertrophy.⁶³

In Brittberg and colleagues' ⁶² original *The New England Journal of Medicine* article describing ACI, 14 of 16 patients who were treated for distal femoral lesions had good to excellent clinical results. Later, the investigators published 2-year to 9-year follow-up data on their first 101 patients treated with ACI and reported 92% good to excellent results for individuals with isolated femoral condylar lesions.⁶⁴ For MACI, many studies have also shown significant improvement in clinical outcome scores and knee function at 2-year to 7-year follow-up.^{65,66}

Imaging studies—MR imaging performed shortly after ACI can demonstrate hyperintense repair cartilage, fluid signal at the interface between repair and native cartilage, and subchondral marrow edema (Figs. 9 and 10).^{17,67,68} Over time, the signal intensity of the repair cartilage normalizes, the marrow edema decreases, and there is progressive peripheral integration of repair cartilage with adjacent native hyaline cartilage as demonstrated by a lack of high T2 signal interposed between the two tissues.⁶⁸ This process can take up to 2 years to complete.

MACI has been studied using T2 mapping and, similar to native hyaline cartilage, there is spatial variation in the T2 values of repair cartilage (although the increase in mean T2 values from deep to superficial layers of cartilage is less pronounced).³⁰ During the first year after the procedure, global mean T2 values of MACI repair tissue can be elevated^{69,70}; over time, T2 values decrease and approach that of native hyaline cartilage.^{69,71} Recently, Welsch and colleagues⁷² reported that T2 mapping can distinguish between MACI performed using a collagen-based scaffold and a hyaluronan-based scaffold (higher T2 values in collagen-based scaffolds) even at 2 years after the original procedure. The investigators concluded that these differences in the MR imaging appearance of cartilage repair tissue should be taken into account when evaluating patients after MACI.

In recent years, there have also been several studies demonstrating a benefit of using dGEMRIC as a noninvasive method to monitor cartilage repair tissue formed after ACI.^{32,73–77} In general, these studies have shown that in the immediate postoperative period, dGEMRIC can differentiate repair tissue from normal hyaline cartilage and suggest that dGEMRIC can be used as a means to evaluate the proteoglycan content of cartilage repair tissue. In a recent study with 9-year to 18-year follow-up of 31 patients who underwent ACI, dGEMRIC indices normalized between repair tissue and native hyaline cartilage, suggesting that proteoglycan content and perhaps the quality of the two tissues is similar.⁷⁸

SUMMARY

As long as people remain physically active, cartilage injury will continue to represent a major clinical problem for orthopedic surgeons, rheumatologists, and other physicians who treat musculoskeletal disorders. There are currently many surgical options available to repair and restore damaged articular cartilage, including microfracture, osteochondral autografting or allografting, repair with synthetic resorbable scaffolds, and ACI (including MACI). Knowledge of the type of repair performed can be useful to interpretation of the MR imaging examination. In the current clinical realm, orthopedic surgeons rely on MR imaging to identify the number, size, and depth of cartilage lesions at the time of initial injury and to assess the status of cartilage repair tissue from a structural standpoint (surface congruency, peripheral integration, cartilage morphology, and presence of subchondral marrow edema). These parameters are typically correlated with patient clinical outcomes to determine whether or not a procedure has been successful. In the future, imaging techniques, such as T2 mapping, dGEMRIC, and sodium MR imaging, have the potential to provide novel information regarding the biochemical composition of the repair tissue matrix, in particular, its collagen, water, and proteoglycan content. This information may help guide decision making by providing clinicians with metrics of the repair tissue quality and physiologic status in addition to its morphologic structure.

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Fig. 1.

A 55-year-old man who underwent microfracture repair. (A) Preoperative, axial, T2-weighted, fat-suppressed, 3-T MR imaging of the knee demonstrates a full-thickness cartilage defect within the lateral femoral trochlea (*arrow*) with extensive surrounding bone marrow edema. (B) Three-month postoperative, axial, T2-weighted, fat-suppressed, 3-T MR imaging demonstrates partial filling of the defect with fibrocartilage (*arrow*), which has an irregular surface and demonstrates fissuring. There is also decreased surrounding bone marrow edema. (C) Six-month postoperative, axial, 3-D, gradient-echo, T1-weighted, fat-suppressed, 7-T MR imaging (0.234 mm × 0.234 mm × 1 mm) shows slightly irregular fibrocartilage filling the defect (*arrowhead*) which has similar signal intensity characteristics to the adjacent native hyaline cartilage. (D) Six-month postoperative, axial, 7-T, sodium MR imaging reveals apparent decreased sodium signal (and thus proteoglycan content) within the fibrocartilage (*arrowhead*). Note the higher sodium signal within the adjacent native hyaline cartilage. Sodium chloride phantoms are seen at the medial aspect of the knee.

Fig. 2.

A 54-year-old woman who underwent microfracture repair. (A) Preoperative, coronal, T2-weighted, fat-suppressed, 3-T MR imaging of the knee reveals a full-thickness cartilage defect within the posterior weight-bearing aspect of the lateral femoral condyle (*arrow*). (B) Six-month postoperative, coronal, T2-weighted, fat-suppressed, 3-TMR imaging shows partial filling of the defect with fibrocartilage (*line*) that is heterogeneous in signal intensity.

Fig. 3.

A 37-year-old woman who underwent osteochondral autografting. (A) Preoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR imaging of the ankle demonstrates an osteochondral lesion of the medial talar dome (*arrow*). There is cartilage damage, mild cortical depression, and subchondral edema/cyst formation. (B) Six-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR imaging shows restoration of the talar dome, including a thin layer of overlying cartilage (*arrowhead*) with similar signal characteristics to adjacent native hyaline cartilage and mild perigraft edema (*arrow*).

Fig. 4.

A 27-year-old woman who underwent osteochondral autografting. (A) Preoperative, coronal, T2-weighted, fat-suppressed, 3-T MR imaging of the knee shows a full-thickness cartilage defect within the weight-bearing aspect of the medial femoral condyle (*arrow*) with surrounding subchondral bone marrow edema. (B) Three-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR imaging shows removal of two osteochondral plugs from the lateral femoral trochlea (*arrow*). (C) Three-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR imaging shows marrow hyperintensity surrounding the transplanted osteochondral autografts (*bracket*). This perigraft edema later decreased at 6-month follow-up.

Fig. 5.

A 19-year-old man who underwent osteochondral autografting. (A) Preoperative, coronal, T2, fat suppressed, 3-T MR image of the knee demonstrates an osteochondral lesion within the weight-bearing aspect of the medial femoral condyle (*arrow*). (B) Six-month postoperative, sagittal, 3-D, gradient-echo, T1-weighted, fat-suppressed, 7-T MR image ($0.234 \text{ mm} \times 0.234 \text{ mm} \times 1 \text{ mm}$) shows an intact osteochondral autograft (*arrow*) with incorporation into surrounding subchondral bone. (C) Six-month postoperative, sagittal, 7-T, sodium MR image shows no detectable differences in cartilage sodium signal (and thus proteoglycan content) within the osteochondral autograft (*arrowhead*) when compared with adjacent native hyaline cartilage.

Fig. 6.

A 50-year-old man who underwent osteochondral allografting. (A) Preoperative, sagittal, T2-weighted, fat-suppressed, 3-T, MR image of the knee shows a large full-thickness cartilage defect at the junction of the weight-bearing and posterior aspects of the medial femoral condyle (*bracket*). (B) Three-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR image shows placement of the osteochondral allograft. The cartilage surface is congruent (*arrow*), and there is extensive graft and perigraft edema.

Fig. 7.

A 36-year-old woman who was treated with a resorbable synthetic scaffold composed of polyglycolide-polylactide. (A) Preoperative, coronal, T2-weighted, fat-suppressed, 3-T, MR image of the knee shows a near full-thickness cartilage defect at the junction of the weight-bearing and posterior aspects of the lateral femoral condyle (*arrow*). (B) Seven-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR image shows that the graft is slightly hyperintense (*black arrow*) when compared with adjacent native hyaline cartilage. The graft remains congruent with the articular surface, and there is no perigraft marrow edema.

Fig. 8.

A 41-year-old man who was treated with a resorbable synthetic scaffold composed of polyglycolide-poly lactide. (A) Preoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR image of the knee shows a full-thickness cartilage defect within the posterior weight-bearing aspect of the medial femoral condyle (*arrow*). (B) Three-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR image shows hyperintense signal within and surrounding the graft. The graft does not appear to be congruent with the articular surface, and no overlying hyaline articular cartilage is visible (*arrow*). (C) Eighteen-month, sagittal, T2-weighted, fat-suppressed, 3-T MR image shows that the degree of intragraft and perigraft edema has greatly decreased. The graft appears to be incorporated into the surrounding subchondral bone, and an overlying layer of hyaline cartilage is visible (*arrowhead*).

Fig. 9.

A 50-year-old man who underwent ACI for a previously unsuccessful microfracture procedure. (A) Preoperative, sagittal, T2-weighted, fat-suppressed, 3-T, MR image of the knee shows a full-thickness cartilage defect within the weight-bearing aspect of the medial femoral condyle (*arrow*). (B) Six-month postoperative, sagittal, T2-weighted, fat-suppressed, 3-T MR image shows the cartilage defect partially filled in with repair tissue. At this stage, the surface of the cartilage repair tissue is slightly irregular (*arrowhead*), and a small cyst is seen within the subchondral bone marrow deep to the repair tissue (*arrow*).

Fig. 10.

A 24-year-old man who underwent ACI for a previously unsuccessful microfracture procedure. (A) Preoperative, coronal, T2-weighted, fat-suppressed, 3-T MR image of the knee shows an anterior cruciate ligament reconstruction and irregular fibrocartilage at the weight bearing aspect of the medial femoral condyle in the region of a previous microfracture (*arrow*). (B) Three-month postoperative, coronal, T2-weighted, fat-suppressed, 3-T MR image shows the cartilage defect partially filled in with hyperintense cartilage repair tissue (*black arrow*) with mild underlying subchondral bone marrow edema. Incidental note is made of a postsurgical fluid collection at the medial aspect of the knee (*arrowhead*).