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Magnetic Resonance Imaging Appearance of Cartilage Repair in the Knee

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Assessment of surgically repaired cartilage lesions with standardized cartilage sensitive magnetic resonance imaging was done to evaluate the integrity, morphologic features, and signal of the articular surface, thereby obtaining information about the natural history of these procedures in the knee. Magnetic resonance imaging also assessed the interface between the repaired and native cartilage, changes in the subchondral bone, and the appearance of cartilage over the opposite and adjacent (native) surfaces. One hundred eighty magnetic resonance imaging examinations were obtained in 112 patients who had cartilage-resurfacing procedures, including 86 microfractures and 35 autologous chondrocyte implantations, at a mean of 15 and 13 months after surgery, respectively. Autologous chondrocyte implantations showed consistently better fill of the defects at all times compared with microfracture. The graft hypertrophied in 63% of surgeries. The repair cartilage over the microfracture generally was depressed with respect to native cartilage. Propensity for bony overgrowth was most marked in the microfracture group, with loss of adjacent cartilage evident with progressive followup.

Magnetic resonance imaging (MRI) provides a noninvasive, accurate assessment of chondral lesions of the knee.[16] With the development of surgical cartilage repair procedures, MRI can provide information about the natural history of cartilage repair. The current study presents MRI data, with as much as 5 years followup, of repaired cartilage defects using microfracture and autologous chondrocyte implantation techniques. Because MRI has direct multiplanar capabilities and high soft tissue contrast, morphologic features of cartilage can be accurately and reproducibly assessed.[5,16] By using a cartilage sensitive sequence, cartilage can be distinguished from adjacent joint fluid and subchondral bone, and its signal characteristics can be determined, which reflect its histopathologic state. Autologous chondrocyte implantation is a procedure that frequently is used for larger cartilage defects than microfracture, as areas from 4.3 cm^2 to 11.66 cm^2 have been transplanted.[11] To obtain information about these procedures after implantation, second look arthroscopy may be done; however, this is invasive and often not accepted by patients. Noninvasive MRI may define the natural history of cartilage repair procedures, potentially obviating the need for arthroscopy.

Microfracture is a marrow stimulation technique used at the site of cartilage loss, whereby the subchondral bone is broached by small picks with the release of stem cells into the cartilage defect, and these cells differentiate into repair cartilage with time.[6,12,18,19] Microfracture largely leads to the development of fibrocartilage at the site of the repair.[12] It is anticipated that the signal characteristics of reparative fibrocartilage will be different from articular hyaline cartilage. Because microfracture involves the release of pluripotent stem cells, differentiation into bone and cartilage may occur. The current study observed the frequency of bony overgrowth and evidence of cartilage injury to the opposite chondral surface as a result of bony impaction by this area of subchondral bony overgrowth.

Autologous chondrocyte implantation involves the harvest of autologous chondrocytes, their culture, and reimplantation at the time of subsequent arthrotomy. Chondrocytes are secured by a periosteal patch.[4,6,11] Previous investigators have noted that overgrowth of the graft may occur.[12,13] Magnetic resonance imaging can evaluate for frequency of graft hypertrophy and determine if the hypertrophy is eccentrically positioned adjacent to the periosteum rather than the matrix adjacent to the subchondral bone. Magnetic resonance imaging also can assess the

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natural history of the periosteal graft, where areas of periosteal detachment or incorporation can be evaluated. This information may be used to gain an objective evaluation of the natural history of cartilage repair.

MATERIALS AND METHODS

Patient Selection

Patients who had MRI at our institution for assessment of a cartilage repair procedure were included in the current study. Patient data were collected in two groups. In 1998, a retrospective review of patients to 1994 was made. This group includes 72 patients who continue to be followed up. From 1998, an additional cohort of patients was identified at the time of the cartilage repair procedure and was followed up prospectively. This group included 40 patients. There were 120 chondral lesions treated in these 112 patients. Six patients had two chondral lesions and one patient had three chondral lesions. Magnetic resonance imaging evaluated 86 microfractures and 35 cartilage transplants (Table 1).

Of the 80 patients who had microfractures, 22 patients (24 microfracture procedures) had MRI at two followups and one patient (one microfracture procedure) had MRI at three followup intervals. The other patients had MRI at one followup interval. Of the 34 patients with cartilage transplants, patients who had more than one followup MRI, 15 patients (15 lesions) were followed up with two MRI scans, five patients (six lesions) had three followup MRI scans, and two patients (two lesions) had four followup MRI examinations. The age range of the patients in the study was 15–65 years, with a mean age of 36.5 years. There were 85 males and 27 females in the study. The study was approved by the institutional review board.

Magnetic Resonance Imaging

Magnetic resonance imaging was done on a 1.5-Tesla magnet (Signa-Horizon LX; General Electric Medical Systems, Milwaukee, WI) using either a linear receive-only knee extremity coil or a transmit and receive phased-array coil (transmit-receive knee PA coil, Med Rad, Milwaukee, WI). Fast spin-echo images were obtained in three planes to assess articular cartilage using a previously validated cartilage sensitive pulse sequence.[16] Each sequence was done with a long repetition time of 3500–5000 ms, a moderate effective echo time of 34–40 ms, an echo train length of 8–14, a bandwidth of 20.8–32 kHz, and a slice thickness of 3–4 mm with no interslice gap. Sagittal images were done with a 512 × 384 matrix and a field of view of 15–16 cm. Axial images were done with a 512 × 256 matrix and a field of view of 14 cm, and coronal images were done with a 512 × 256–288 matrix and a field of view of 11–15 cm. In addition, a sagittal fat suppressed sequence was obtained to evaluate the subchondral bone, using either a fast spin-echo sequence with frequency selective fat suppression (repetition time of 4000 ms, echo time of 40 ms) or short tau inversion recovery sequence (repetition time of 6950 ms, echo time of 22 ms, and time to inversion of 150 ms).

The MRI scans were analyzed by a senior musculoskeletal radiologist and an MRI fellow. Images were assessed for: relative signal intensity from the repaired area compared with the native cartilage; morphologic features of the repaired area (flush, proud, or depressed with respect to native cartilage); delamination (in the case of autologous chondrocyte implantation); nature of the interface (presence, absence, size of fissures) with the adjacent (native) surface and percent fill of the lesion by thirds. Percent fill was assessed by determining volume filling of the defect using coronal and sagittal images. Fissures were assessed as being small (< 2 mm) or large (> 2 mm). Hypertrophy of the graft was assessed in the case of autologous chondrocyte implantation and an attempt was made to determine whether this was attributed to hypertrophy of the periosteal cover, the contents of the graft, or both. The periosteum was defined as hypertrophic when it measured greater than 1 mm. Assessment of periosteal integrity also was made and it was determined whether it was intact, partially detached, fully detached, partially incorporated, or fully incorporated. Incorporation occurred when the margin between the cover and the underlying cartilage became indistinct. Integrity of the cartilage over the opposite and adjacent (native) surfaces was graded using the modified Outerbridge classification.[14] The presence or absence of bony overgrowth was noted. The presence or absence of subchondral edema and fat pad scarring was evaluated as mild (< 1 cm^2), moderate (1–3 cm^2), or severe (> 3 cm^2). Results of MRI were tabulated within 6 months, 6–18 months, and greater than 18 months from the date of the surgical procedure to assess for trends.

Statistical comparisons of the two cartilage repair techniques were done using chi square statistics with $p < 0.05$ being statistically significant. Only limited comparison was made because of the small sizes of the subgroups, the lack of concurrent comprehensive clinical outcome assessment, and the heterogeneity of the patient sample (the patients were not identical groups that had different treatments).

TABLE 1. Patient Selection

Repair Technique	MRI Scans	Patients (# = 112*)	Lesions (# = 120*)	Followup (months) (average)
Autologous chondrocyte implantation	68	34	35	0.7–53.2 (average–13 month)
Microfracture	112	80	86	0.2–62.1 (average–15 month)

*Two patients are in the autologous chondrocyte implantation and microfracture group. One patient had a lesion treated by two techniques and one patient had two lesions treated by different techniques.

RESULTS

Autologous Chondrocyte Implantation

In the autologous chondrocyte implantation group, 34 patients had 35 procedures. These procedures were evaluated by 68 MRI scans. Evaluation by MRI occurred between 0.7–53.2 months after surgery, and the mean followup was 13 months.

Of the 34 patients, five patients (eight MRI scans) had grafts that became displaced or delaminated from the subchondral bone. The displacement was seen on the first followup MRI scans in each patient. Displacement was present on MRI scans obtained at 6 weeks (two patients), 4 months (one patient), 7 months (one patient), and 9 months (one patient) after the date of autologous chondrocyte implantation surgery. The chondral lesions were located on the medial femoral condyle (two patients), lateral femoral condyle (two patients), and the trochlea (one patient). Graft delamination was partial (one case) or complete (four cases). Resultant chondral defects measured as much as 2.5 × 1.5 cm. In one of these patients, there was a chondral defect over the lateral femoral condyle with a loose body anterior to the trochlea. This patient had subsequent microfracture of the area of exposed bone. In another of these patients, a chondral defect was present over the trochlea and debris, likely representing chondral fragments, was present in the joint. One of the patients had partial delamination of a transplant over the medial femoral condyle with a chondral flap and joint fluid extending between the transplant and the subchondral bone (Fig 1).

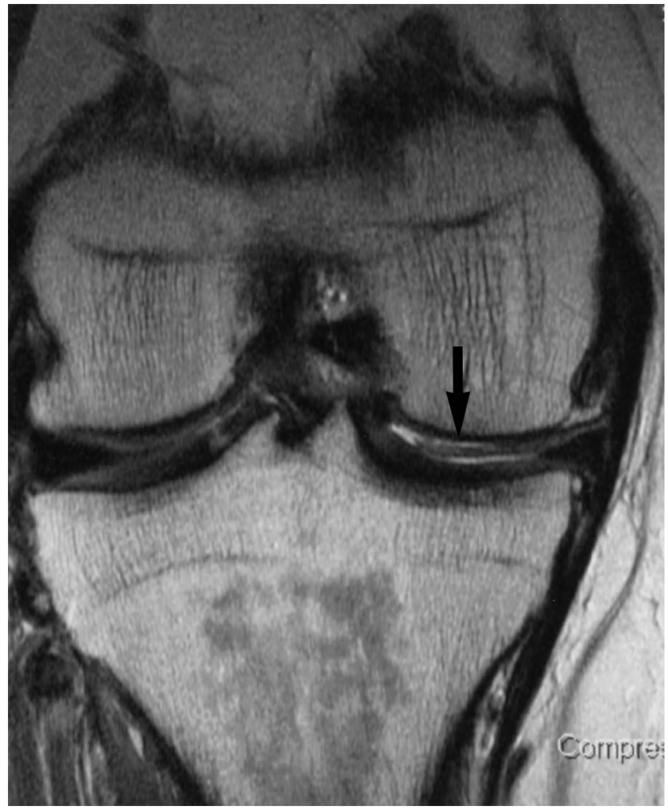

Fig 1. A coronal MRI scan of a 40-year-old man, obtained 7 months after autologous cartilage implantation, shows partial delamination of a transplant (arrow) over the medial femoral condyle with an articular flap and joint fluid extending between the transplant and the subchondral bone.

Thirty patients had grafts that remained intact (one patient had two autologous chondrocyte implantations, one of which remained intact) and these were assessed by 60 MRI scans. Twenty-two MRI scans were done within 6 months after surgery, 22 MRI scans were done between 6–18 months after surgery, and 16 MRI scans were done greater than 18 months after surgery. The grafts were located on the medial femoral condyle in 19 patients, the trochlea in six patients, the lateral femoral condyle in four patients, and the patella in one patient.

All grafts were hyperintense to articular cartilage on MRI scans (22 of 22) done less than 6 months after surgery, 73% (16 of 22) were hyperintense at longer term followup (6–18 months), and 69% (11 of 16) were hyperintense greater than 18 months after surgery. The remaining grafts were isointense and no grafts were hypointense to hyaline cartilage (Fig 2).

At all times, the majority of the grafts seen on MRI (43 of 60) were not flush with the articular surface and either could be depressed (23 of 60) or proud (20 of 60). There was a trend in the morphologic features of the graft. At shorter term followup (< 6 months) grafts were more likely to be proud with respect to native cartilage (proud on nine of 22 MRI scans, flush on eight of 22 MRI scans, and depressed on five of 22 MRI scans done < 6 months after surgery). Later, grafts most likely were depressed relative to articular cartilage (depressed on nine of 16 MRI scans, flush on four of 16 MRI scans, and proud on three of 16 MRI scans done > 18 months after surgery). Between 6–18 months after surgery, grafts could be depressed (nine of 22 MRI scans) or proud (eight of 22 MRI scans) with the remaining five of 22 MRI scans having a flush surface between the graft and native cartilage. Of the grafts that initially were proud and the patients had followup MRI scans, four of 10 were depressed on subsequent scans (only one of these had interval debridement), two of 10 were flush (one of which was debrided), and four of 10 remained proud (two of which had debridement), indicating a variable remodeling of the initially proud grafts.

The fate of the periosteal graft was evaluated using only MRI scans that were done before any debridement procedures (Table 2). Two patients had debridements before followup MRI and therefore were excluded from assess-

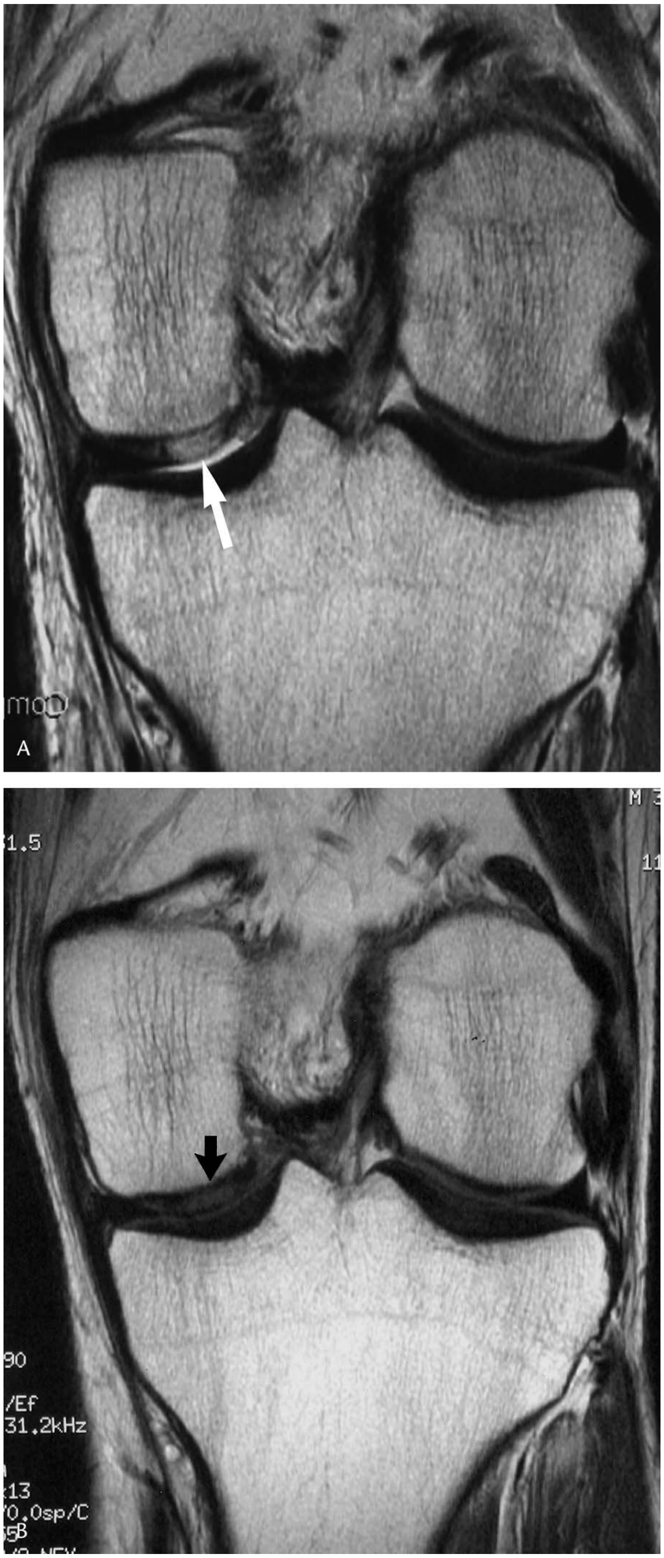

Fig 2A–B. Coronal MRI scans of a 31-year-old man were obtained (A) 6 weeks and (B) 20 months after autologous chondrocyte implantation. Figure 2A shows a hyperintense graft with an intact, hypointense periosteal graft (arrow). Figure 2B, obtained at the same coronal level, shows isointense repair cartilage, with incorporation of the periosteum to the cartilage, such that the periosteal cover is indistinct (arrow).

TABLE 2. Fate of Periosteal Graft

Periosteum	Patients (n = 28)	Mean Time (Months)
Partial detachment	8	6.0
Full detachment	6	10.1
Intact	12	9.5
Partial incorporation	1	4.9
Full incorporation	1	5.5

ment. Of the remaining 28 patients, eight patients had periosteal grafts that became partially detached and in six patients, the periosteum was detached fully. On average, this occurred as early as 6 and 10.1 months, respectively. Twelve patients had periosteal flaps that remained intact and this was, on average, present as late as 9.5 months after autologous chondrocyte implantation surgery. Two patients, on initial followup MRI at 4.9 and 5.5 months, had partial and full incorporation, respectively. Two of the patients who had an intact periosteum on subsequent MRI scans had partial incorporation in one case and full incorporation of the periosteum to the underlying cartilage in the second case.

The graft hypertrophied in 63% (19 of 30) of surgeries and this could occur at any time, but first was seen most commonly in the less than 6 months group (13 of 19) (Fig 3). There could be hypertrophy of the repair cartilage (12 of 19), the periosteum when apparent as separate from the cartilage matrix (four of 19), or of the repair cartilage and periosteum (three of 19). Hypertrophy was overrepresented in the grafts located on the medial femoral condyle, with 79% (15 of 19) of cases of hypertrophy occurring at this site. Of the patients who had hypertrophy, 84% (16 of 19) had osteochondritis dissecans (14 patients) or prior osteonecrosis (two patients). Of patients with hypertrophy, eight required debridement of the periosteum, debridement of repair cartilage, or both.

Subchondral bone marrow edema generally was mild (51 of 60) or moderate (eight of 60) with only one MRI scan showing severe edema. In this patient, this was not related to the degree of uncovering of the subchondral bone, as the patient had good fill of the chondral defect.

Bony overgrowth by the subchondral plate was present on 11 MRI scans (seven patients). One of these seven patients had a previous microfracture and one had a previous drilling procedure. All of these patients required followup surgery. Most notably, this included microfracture in two patients, osteotomy in one patient, and total knee arthroplasty in a fourth patient. Two other patients had areas distant from the autologous chondrocyte implantation debrided and one patient had the graft and periosteum debrided.

Fig 3. A coronal MRI scan of a 15-year-old boy, obtained 3 months after autologous cartilage implantation, shows hypertrophy of the graft overlying the medial femoral condyle with extension toward the intercondylar notch. There is apparent hypertrophy of the periosteal cover and cartilage matrix.

The interface with the adjacent cartilage was rarely smooth (four of 60 MRI scans), with fissures less than 2 mm seen on 25 of 60 MRI scans and fissures greater than 2 mm seen on 31 of 60 MRI scans. No patient had a smooth interface on all followup MRI scans. Percent fill of the defect by the graft was generally good, with 44 of 60 MRI scans showing 67–100% fill, 13 of 60 MRI scans showing 34–66% fill, and three of 60 MRI scans showing 0–33% fill. Outerbridge grading[14] of cartilage adjacent and opposite the autologous chondrocyte implantation was tabulated, and changes in Outerbridge grading of adjacent and opposite cartilage with time were not statistically significant. There were nine patients who had Grade 3 or 4 cartilage lesions opposite the repair and of these, five had overgrowth of the subchondral bone. Fat pad scarring was mild (29 of 60), moderate (27 of 60), or severe (four of 60).

Where possible, it was recorded when patients required additional surgery after cartilage transplantation. Of the 34 patients, 21 patients had additional surgery at this institution, which included 35 procedures. This included 25 debridements. Of the debridements, the cartilage transplant was debrided in six patients, the periosteum was debrided in eight patients, and in three patients, the transplant and the periosteum were debrided. The remainder of the patients had other areas such as the synovium or fat pad debrided, or had more extensive debridement of multiple chondral surfaces, sometimes including the area of cartilage transplantation. In addition, three patients had subsequent microfractures at the time of debridement and two patients had meniscectomies at the time of debridement. Other procedures included three osteotomies and two total knee replacements. Minor procedures done in five patients included two knee manipulations, removal of hardware, cartilage biopsy, and a synovial biopsy.

Microfracture

In the microfracture group, 80 patients had 86 procedures evaluated by 112 MRI scans. Evaluation by MRI occurred between 0.2–62.1 months after surgery. The mean followup was 15 months. Twenty-nine MRI scans were done within 6 months of surgery, 52 MRI scans were done between 6–18 months, and 31 MRI scans were done greater than 18 months after surgery. Microfractures were present at the following sites; medial femoral condyle (50), lateral femoral condyle (16), trochlea (12), patella (five), lateral tibial plateau (two), and medial tibial plateau (one).

The covering reparative material was hyperintense (97 of 112) mainly, isointense on 10 of 112 MRI scans, and hypointense on five of 112 MRI scans. The morphologic features most frequently were depressed (66 of 112) with respect to surrounding cartilage, but could be flush (27 of 112) or proud (19 of 112) (Fig 4). Subchondral edema was mild (94 of 112) or moderate (18 of 112), and there were no cases of severe subchondral edema.

Propensity for bony overgrowth was most marked in the microfracture group and was seen in 42 of 86 microfractures. Fissures between the area of microfracture and adjacent cartilage invariably were present, as the interface was seen as smooth on only five of 112 MRI scans. Fissures were seen as greater than 2 mm in 59 of 112 MRI scans and less than 2 mm in 48 of 112 MRI scans. Percent fill of the defect was variable, ranging from good (67–100%) as seen on 53 of 112 MRI scans, moderate (34–66%) on 30 of 112 MRI scans, and poor (0–33%) on 29 of 112 MRI scans. For patients who had at least two postoperative MRI scans (25 lesions in 23 patients), the percent fill of the defect increased with time; however, bony overgrowth was present in 12 of the patients who had at least two MRI scans. Worsening of Outerbridge grading of adjacent cartilage occurred during the duration of followup. No trend in change with time in Outerbridge grading of the opposite cartilage was evident. Fat pad scarring generally was mild (91 of 112), with some cases of moderate (19 of

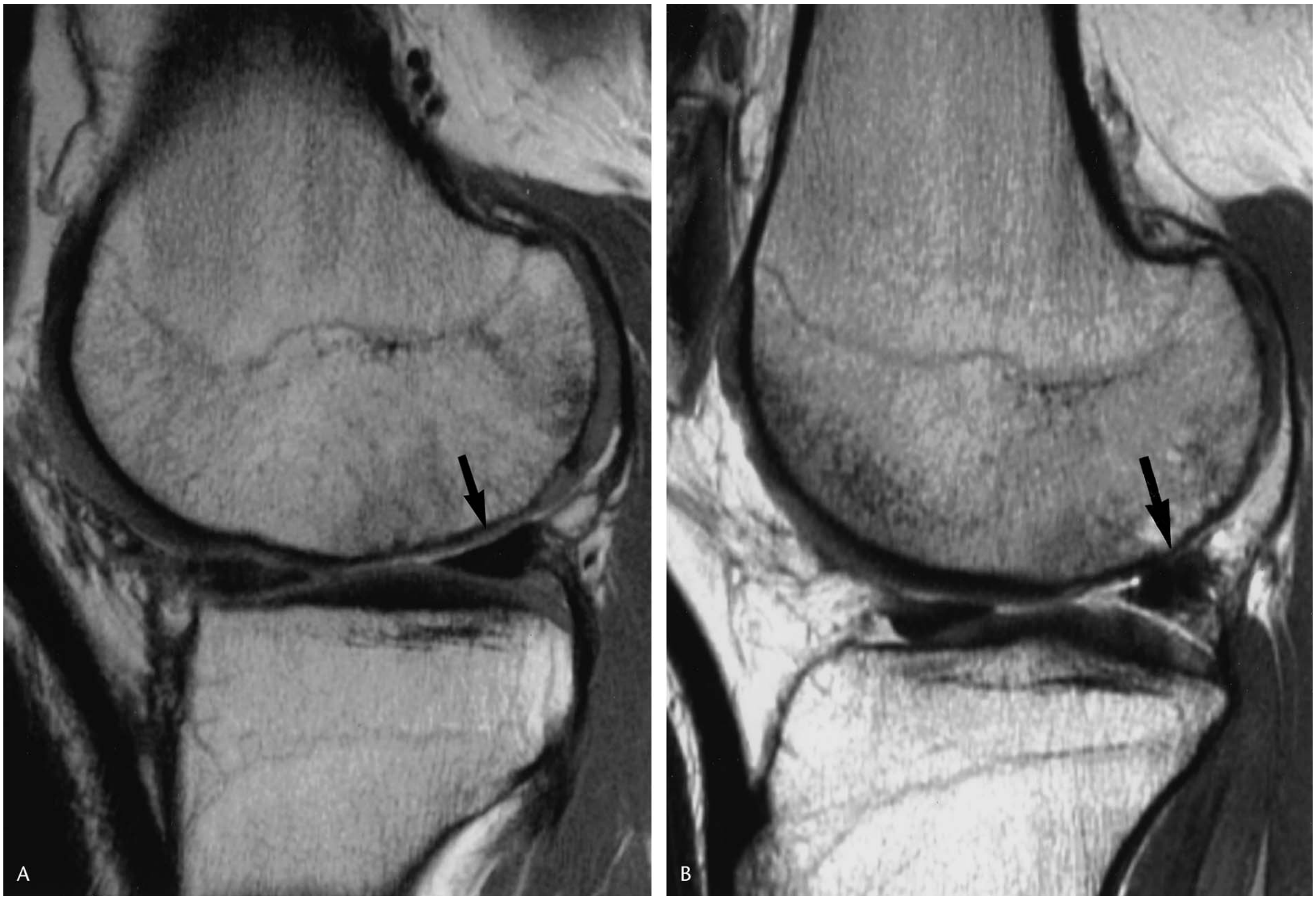

Fig 4A–B. Sagittal MRI scans of a 30-year-old man were obtained (A) 3 months and (B) 15 months after microfracture. Figure 4A shows a thin rind of hyperintense reparative cartilage (arrow), which is depressed with respect to adjacent cartilage. Figure 4B shows little remaining repair cartilage over the posterior aspect of the lateral femoral condyle with irregularity of the subchondral plate (arrow).

112) fat pad scarring. Severe fat pad scarring was rare (two of 112).

Eight patients required nine followup surgeries. The surface was debrided in seven surgeries. One patient had a debridement and partial meniscectomy and one patient had a meniscal allograft inserted. Salient findings comparing autologous chondrocyte implantation and microfracture were tabulated (Table 3).

TABLE 3. Comparison of Microfracture with Autologous Chondrocyte Implantation

Sequelae of Cartilage Repair	Microfracture	Autologous Chondrocyte Implantation	Values (Chi square Statistics)
Percent fill good (67–100%)	47% (53 of 112 MRI scans)	73% (44 of 60 MRI scans)	=0.00003
Fissures > 2 mm	53% (59 of 112 MRI scans)	52% (31 of 60 MRI scans)	=0.90
Morphologic features, depressed	59% (66 of 112 MRI scans)	38% (23 of 60 MRI scans)	=0.01
Morphologic features, proud	17% (19 of 112 MRI scans)	33% (20 of 60 MRI scans)	=0.02
Bony overgrowth	49% (42 of 86 microfractures)	23% (7 of 30 autologous chondrocyte implantations)	=0.02
Hypertrophy	Not applicable	63% (19 of 30 patients)	Not applicable
Periosteal detachment	Not applicable	50% (14 of 28 patients)	Not applicable

DISCUSSION

The intention of the current study is to provide the practicing surgeon who does cartilage repair surgery with a guideline with respect to the MRI appearance of cartilage repair. This study provides the most comprehensive MRI evaluation of cartilage repair to date. Typical appearances are quantified and described, thereby providing information about the imaging appearance and natural history of cartilage repair.

Before discussing specific features of cartilage repair that were observed it is important to note some limitations of the current study. The purpose of this retrospective study was to comment on the morphologic features and provide an evaluation of the MRI appearance of cartilage repair techniques at different intervals after surgery. Longitudinal changes with time were difficult to quantify because the dates at which the evaluations were made were not standardized in all patients. The current study provides a guideline with respect to the anticipated appearance of these cartilage repair techniques seen with MRI.

The purpose of the current study was to provide an objective assessment of cartilage repair procedures, to serve as an adjunct to the more subjective clinical outcome scores. The lack of clinical correlation limits the ability to comment on the prognostic clinical significance of the MRI findings, but does not detract from the ability of standardized MRI to assess the morphologic features of cartilage repair. A study of 44 patients in which the patient's function was measured by clinical score showed that autologous chondrocyte implantation improved quality of life during the first year of followup and gains were maintained through the second year.[10] Evaluation that is limited to clinical outcome scores, however, does not provide an objective measure of treatment outcome, and limits the ability to gain a more comprehensive assessment of the biologic features of cartilage repair. The presence of subchondral bony overgrowth after microfracture, for example, may not be reflected in early clinical scores or be seen at arthroscopy, but conceivably may contribute to subsequent cartilage loss by bony impaction of the opposite chondral surface. Therefore it is important that these features are recognized and followed up with time. The validity of our approach lies in the comprehensive and systematic way in which data has been collected from all postoperative MRI scans, using an identical MRI protocol with relatively high in-plane resolution, and then tabulated.

Magnetic resonance imaging scans were not interpreted in a blinded fashion according to treatment. The senior radiologist has a specific interest in cartilage imaging, and it was impossible to blind this radiologist, based on the distinct MRI appearance of autologous chondrocyte implantation versus microfracture. In addition, statistical comparisons of the two cartilage repair techniques must be interpreted with caution because the study mainly is a retrospective review of cartilage repair techniques done for different indications, and is not intended as a comprehensive comparison of microfracture to autologous chondrocyte implantation.

Regarding autologous chondrocyte implantation, 14% of procedures in 34 patients (35 lesions) in the current study delaminated from the underlying subchondral bone, with delamination occurring early during the postoperative course, typically within 9 months of surgery. A pattern of complete and partial delamination was described, resulting in a full thickness defect or absence of part of the graft, with or without fluid signal between the graft and subchondral bone.[1,2,20] Indirect MR arthrography using fat suppressed T_1-weighted images after intravenous gadolinium-diethylenetriaminepentaacetic acid (Gd-DTPA) has been used to identify a line of enhanced joint fluid beneath the repair tissue, thereby diagnosing delamination.[1,2,20] These authors stated that MR arthrography increases specificity for the diagnosis but these findings were not quantified. We previously found that the nonenhanced fluid sensitive pulse sequences used in the current protocol, when done with high in-plane resolution, had high positive and negative predictive values for detection of a traumatic chondral delamination when compared with arthroscopy.[16]

Only three patients (four MRI scans) had a smooth interface between the graft and the adjacent cartilage. Moreover, at other times during their postoperative course, fissures were seen in these patients, thereby making the finding of fissures during the postoperative course of autologous chondrocyte implantation universal in the current group. Alparslan et al[1,2] reported that the interface between the graft and native cartilage may appear as a bright fluid-like line that simulates a fissure, even though the autologous chondrocyte implantation surface usually is intact at arthroscopy. Arthroscopy can assess the cartilage surface, including subjective hardness to probing. However, unlike arthroscopy, MRI can evaluate the central and basilar components of repair cartilage that are not seen at surgery. High resolution MRI techniques are necessary to detect subtle fissures at the repair interface. Although the long-term significance of fissures is unknown, the larger fissures may represent failure of the repair cartilage to integrate with the adjacent hyaline cartilage.

The signal intensity of repair cartilage was largely different than that of hyaline cartilage. Early during the course of autologous chondrocyte implantation, all grafts are hyperintense to hyaline cartilage and some grafts become isointense to hyaline cartilage after 6 months. Alparslan et al[1,2] reported that grafts tend to have a brighter signal early in their course and change with graft maturation. Graft maturation has been discussed in terms of consistency and feel to probing with increasing firmness with time.[15] Moreover, the repair cartilage signal may reflect changes in its composition, as repair cartilage is heterogeneous in composition and usually contains fibrocartilage and hyaline-like articular cartilage.[3,17]

In the current series the periosteal covering became partially or completely detached in 50% of patients. Despite detachment, percent fill of the chondral defect by the graft generally was good, indicating that attachment of the transplanted chondrocytes to subchondral bone had occurred before detachment. The periosteal cover frequently required debridement and accounted for some of the postprocedure morbidity.

In our series, graft hypertrophy was common. Previously, this was attributed to periosteal hypertrophy.[1,2,15,20] The appearance of the hypertrophied grafts in the current patients suggests thickening of matrix in addition to the periosteal cover; however, this finding may reflect the incorporation of the periosteum, allowing for a factitious appearance of matrix enlargement. Hypertrophy of the graft results in a graft that is thicker than the native cartilage. It could be postulated that this might cause wear of the opposite cartilage; however, because of relatively low numbers, no trends in Outerbridge grading[14] of the opposite cartilage were observed. Hypertrophy was more likely to occur with lesions of the medial femoral condyle, particularly in the setting of previous osteochondritis dissecans, where hypertrophy could occur toward the intercondylar notch. The increased incidence at this site may reflect lack of containment by native cartilage, an absence of native cartilage to suture the periosteal flap to, and the presence of a potential space for growth.

The finding of bony overgrowth in patients after cartilage transplantation, although only seen in seven patients in the current group, is associated with a poorer clinical outcome, as evidenced by the subsequent surgeries in these patients.

Percent fill of the defect by autologous chondrocyte implantation generally was good, as reported previously.[1] Percent fill by repair cartilage after autologous chondrocyte implantation was consistently better at all times than that seen after microfracture.

Alparslan et al[2] reported that the microfracture technique is characterized by the early appearance of thin, intermediate signal intensity cartilage in the defect, which overlies high signal in the subchondral bone. In asymptomatic patients there is progressive filling in of the defect and gradual diminution of the bone marrow edema pattern in the subchondral bone.[2] The current study showed that the bone marrow edema pattern generally was mild at all times. The repair cartilage signal generally was hyperintense to that of articular cartilage. This would suggest that, like autologous chondrocyte implantation, the repair cartilage after microfracture has a different composition. Most commonly, the repair cartilage is depressed with respect to articular cartilage and fissures are present between the repair and native cartilage. In the current series, percent fill of the defect increased with time; however, this likely reflects filling of the defect with subchondral bone rather than overgrowth of repair cartilage (Fig 5). Bony overgrowth was common in the current patients, and it is not known what precise mechanism causes this phenomenon. It might be attributable to differentiation of the fibrin clot into bone and cartilage or because of endochondral ossification of the newly formed cartilage, which is expected to occur gradually with time.

While one could speculate that the opposite chondral surface may show wear as a result of impaction by bony overgrowth, there was no change with time in Outerbridge grading[14] of the opposite cartilage surface, likely attributable to the fact that the numbers in the current series are small. A trend toward worsening of Outerbridge grading of the adjacent cartilage and duration of followup was evident. Although reasons for this are unknown, the adja-

Fig 5. A sagittal MRI scan of a 21-year-old man, obtained 13 months after microfracture, shows bony overgrowth (arrow) over the medial femoral condyle at the site of microfracture. The repair cartilage is near flush with the adjacent native cartilage. However, the thickness of the repair cartilage overlying the bony overgrowth is half that of the adjacent native cartilage.

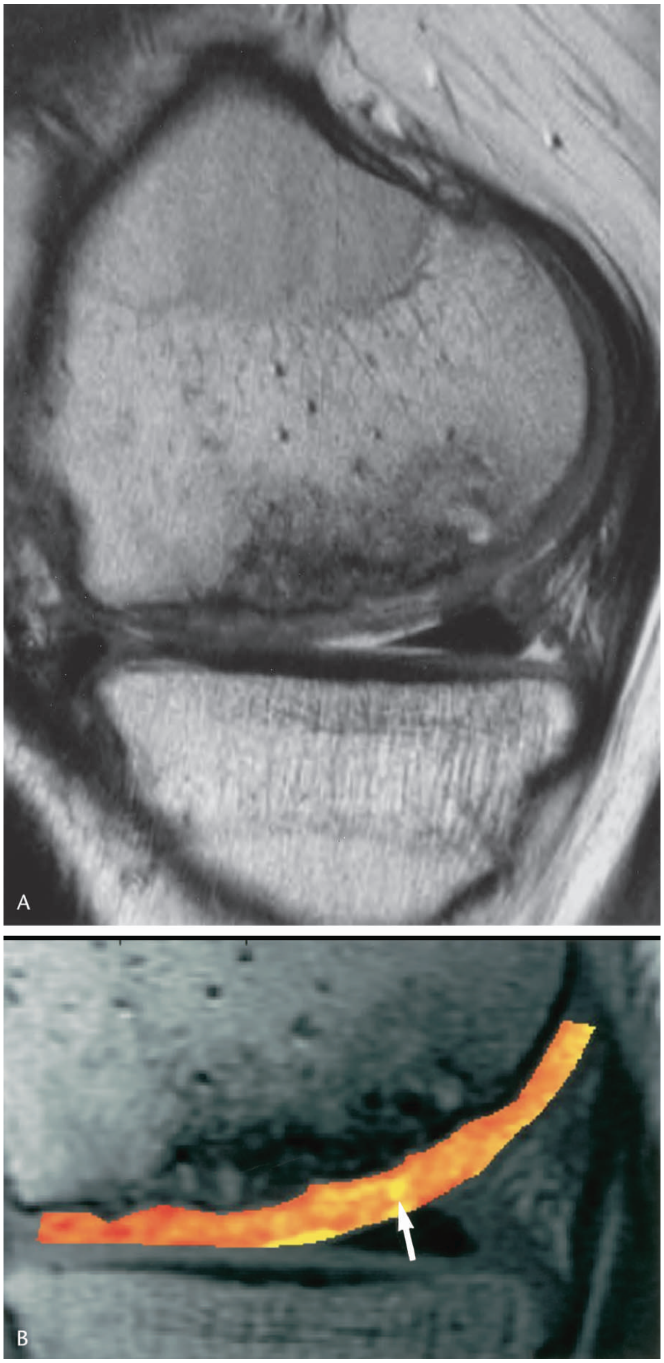

Fig 6A–B. Sagittal MRI scans of a 15-year-old boy were obtained 22 months after autologous chondrocyte implantation, at a site of prior osteochondritis dissecans of the medial femoral condyle. (A) Hyperintense repair cartilage can be seen overlying sclerotic subchondral bone. (B) A T_2 relaxation time map shows lack of normal zonal architecture of the repair cartilage with heterogeneously increased T_2 signal (arrow) throughout the repair.

cent cartilage may see more load if the repaired defect is depressed with respect to the surrounding cartilage, as was seen commonly in the current series of patients.

Several methods of MRI for cartilage repair evaluation have been described.[7,8,20] A standardized cartilage sensitive MRI technique using moderate echo time fast spin-echo imaging was used, which provides good contrast resolution between joint fluid, hyaline cartilage, meniscus, and subchondral bone.[16] More traditional gradient echo techniques may be limited by susceptibility artifact related to postoperative metallic debris.[8,9]

Additional directions include tissue characterization techniques, which will provide insight into the extracellular matrix constituents of the repaired cartilage. Preliminary work by Gillis et al[7] was done using delayed gadolinium-enhanced MRI to evaluate for glycosaminoglycan distribution in cartilage of patients with autologous chondrocyte implantation. At our institution, work is being done on T_2 mapping of cartilage at clinical field strengths (1.5 Tesla). Studies at high field strengths of 7–9 Tesla have shown a relationship between T_2 relaxation time and orientation of the collagen fibers in the extracellular matrix.[21] In hyaline cartilage imaging done at high (7–9 Tesla) field strengths, increasing T_2 relaxation time is observed from the deep radial zone to the intermediate transitional zone and there is an additional increase in T_2 to the superficial zone. T_2 mapping uses the correlation between cartilage water content and T_2 relaxation times to provide information about collagen orientation, zonal structure, and quality. Our current limited experience shows increasing T_2 and heterogeneity of T_2 in repair cartilage, with a lack of the expected T_2 stratification coursing from the subchondral plate to the articular surface (Fig 6).

The current study provides the most comprehensive imaging assessment of cartilage repair. Morphologic features can be assessed accurately and reproducibly, thereby providing the surgeon with a guideline for the MRI appearances of these new and evolving cartilage repair procedures.

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