Treatable Chondral Injuries in the Knee: Frequency of Associated Focal Subchondral Edema

OBJECTIVE. In the knee, chondral flaps and fractures are radiographically occult articular cartilage injuries that can mimic meniscal tears clinically; once correctly diagnosed, these injuries can be treated surgically. We investigated an associated MR imaging finding—focal subchondral bone edema—in a series of surgically proven lesions.

MATERIALS AND METHODS. Two musculoskeletal radiologists retrospectively reviewed the MR studies of 18 knees with arthroscopically proven treatable cartilage infractions, noting articular surface defects and associated subchondral bone edema; subchondral edema was defined as focal regions of high signal intensity in the bone immediately underlying an articular surface defect on a T2-weighted or short inversion time inversion recovery (STIR) image.

RESULTS. The first observer saw focal subchondral edema deep relative to a cartilage surface defect in 15 (83%) of the 18 cases; in two additional cases a surface defect was seen without underlying edema. The second observer identified 13 knees (72%) with surface defects and associated subchondral edema and three with chondral surface defects and no associated edema. Subchondral edema was seen more frequently on fat-suppressed images and on STIR images than on non–fat-suppressed images.

CONCLUSION. Focal subchondral edema is commonly visible on MR images of treatable, traumatic cartilage defects in the knee; this MR finding may prove to be an important clue to assist in the detection of these traumatic chondral lesions.
on T2-weighted and STIR images, and we use this sign to alert us to critically examine the overlying cartilage surface for surface defects. We performed this study to further investigate the association of focal subchondral edema with treatable articular cartilage injuries.

Materials and Methods

We identified cases by a computerized search of our institution’s database. The following inclusion criteria were used: a cartilage defect seen at knee arthroscopy that the operating orthopedist believed to be treatable or potentially treatable; preoperative MR images obtained at our hospital using our routine knee-imaging protocol; and normal findings on preoperative radiographs. The radiographs were used to exclude patients with degenerative lesions and included a weight-bearing, posterior-anterior projection made with the knee flexed, which is highly sensitive for revealing early cartilage degeneration [20]. Knees that showed radiographic osteochondral lesions or any joint-space narrowing were excluded.

From October 1994 through September 1997, arthroscopy for a suspected internal derangement was performed on a total of 578 knees that had also undergone MR imaging. Eighteen of these patients (3%) met our inclusion criteria: 14 men and four women. Patients ranged in age from 18 to 59 years (mean, 31 years). Twelve of the patients (67%) were athletes (college, n = 7; recreational, n = 4; professional, n = 1). American football was the sport in which most patients (n = 6) participated; two patients participated in multiple sports, two played basketball, and one each participated in soccer and running. Eleven patients (61%) recalled specific inciting injuries. Knee pain was present in all but two patients. Eight patients complained of swelling and five had locking or “catching” of the knee. A meniscal tear was the initial suspected clinical diagnosis in 16 patients (89%). The referring physician questioned whether a cartilage injury was present in only two patients before MR imaging.

Arthroscopy was performed by one of four fellowship-trained sports medicine orthopedists, but two of the surgeons who had a special interest in the knee operated 15 (83%) of the 18 procedures. Three of the injuries were chondral flaps (Fig. 1), and the remaining 15 were chondral fractures (separations). Lesions involved the medial femoral condyle in eight knees, the lateral femoral condyle in eight, and the femoral trochlea in two. All the lesions were of full thickness. The size of the chondral defect was not noted in the arthroscopy report of four knees. In the remaining 14 knees, the defect ranged from 3 × 4 mm to 30 × 30 mm. In nine patients the defect measured 1 cm or less in the largest diameter. The mean area of the measured defects was 2.0 cm². Fifteen cases (mean, 31 years). Twelve of the patients (67%) were athletes (college, n = 7; recreational, n = 4; professional, n = 1). American football was the sport in which most patients (n = 6) participated; two patients participated in multiple sports, two played basketball, and one each participated in soccer and running. Eleven patients (61%) recalled specific inciting injuries. Knee pain was present in all but two patients. Eight patients complained of swelling and five had locking or “catching” of the knee. A meniscal tear was the initial suspected clinical diagnosis in 16 patients (89%). The referring physician questioned whether a cartilage injury was present in only two patients before MR imaging.

Fig. 1.—Articular cartilage: normal anatomy and lesions.
A, Drawing shows normal articular surface and subchondral bone.
B, Drawing shows cartilage flap tear. Chondral fragment is typically separated from underlying bone at tidemark and may hinge at one end, opening and closing like a trapdoor. Note sharp margination with normal cartilage at lesion border.
C, Drawing shows chondral fracture (separation). Because fragment is composed solely of cartilage, lesion will be radiographically occult. Fragment may remain in situ or may displace and become intraarticular body.
D, Drawing shows osteochondral fracture or osteochondritis dissecans. Injury involves subchondral bone and will be visible radiographically.
E, Drawing shows advanced chondromalacia or degenerative chondrosis. Lesion margins are indistinct. Angle of lesion wall is shallow compared with wall of cartilage flaps and fractures.
MR Imaging of Chondral Injuries in the Knee

TABLE I  Number of MR Findings Seen by Each Observer, Stratified by Pulse Sequence

<table>
<thead>
<tr>
<th>MR Finding</th>
<th>Spin-Echo T2-Weighted Imaging</th>
<th>Fast Spin-Echo T2-Weighted Imaging with Fat Suppression</th>
<th>Short Inversion Time Inversion Recovery Imaging</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>%</td>
<td>No.</td>
<td>%</td>
</tr>
<tr>
<td>Number of knees</td>
<td>18</td>
<td>%</td>
<td>14</td>
</tr>
<tr>
<td>Observer 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defect with edema</td>
<td>10</td>
<td>56</td>
<td>10</td>
</tr>
<tr>
<td>Defect without edema</td>
<td>7</td>
<td>39</td>
<td>2</td>
</tr>
<tr>
<td>No defect</td>
<td>1</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Observer 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Defect with edema</td>
<td>9</td>
<td>50</td>
<td>9</td>
</tr>
<tr>
<td>Defect without edema</td>
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<td>33</td>
<td>3</td>
</tr>
<tr>
<td>No defect</td>
<td>3</td>
<td>17</td>
<td>2</td>
</tr>
</tbody>
</table>

Fig. 2.—22-year-old man with suspected meniscal tear who was injured playing collegiate football. A, Sagittal spin-echo MR image (TR/TE, 2583/75) through lateral compartment shows sharply marginated, fluid-filled defect in articular surface of lateral femoral condyle (between arrows), which was seen by both observers. Subchondral edema was seen only by observer 1. B, Corresponding fast inversion-recovery MR image (3616/89, inversion time, 186 msec) shows associated subchondral edema within lateral femoral condyle (arrow), which was seen by both observers. C, Arthroscopic image of lateral femoral condyle shows full-thickness cartilage defect with exposed subchondral bone (asterisk). Arthroscopist found this bone to be “abnormally soft” when pick was used to treat defect. Note relatively sharp margins of defect.
matrix size, 256 × 192–256; and number of excitations, 1–2. The echo train length was eight for the T2-weighted fast spin-echo sequences and four for the STIR sequences. Typical imaging times for the MR sequences were 22 min in the first four patients and 26 min for the final 14 patients, excluding the time necessary for setup, patient positioning, and prescanning.

Two radiologists with fellowship training in musculoskeletal imaging reviewed the MR examinations. Coronal and sagittal T2-weighted spin-echo and fast spin-echo sequences and STIR sequences were initially viewed separately, and then each examination was reviewed in its entirety. The two observers worked independently. This study was designed primarily to investigate the association between subchondral bone changes and treatable chondral defects; therefore, for each case the radiologists were told which surface showed the abnormality at surgery. The observers were otherwise unaware of the details of the arthroscopic findings (e.g., depth and diameter of the lesions, location of the defects along the articular surface, type of treatment used) and of the original prospective MR interpretation. For each pulse sequence, each observer noted whether a defect was visible within the articular surface. Subchondral edema was defined as increased signal within the subchondral bone immediately deep relative to a visible cartilage defect, compared with the remainder of the epiphyseal bone marrow, for each pulse sequence. Only areas of marrow edema adjacent to chondral defects were recorded.

Each observer established a final diagnostic category for each knee—no defect, defect without edema, or defect with edema—after viewing all the pulse sequences based on the images that showed the most prominent findings. Interrater agreement was assessed using the kappa statistic. The original MR imaging reports were reviewed to determine how frequently cartilage injuries had been initially suggested.

**Results**

Table 1 shows the frequency of findings reported by the observers. Both observers frequently saw areas of focal subchondral edema associated with a defect in the overlying articular surface (Fig. 2). Subchondral edema was noted most frequently on the STIR and fat-suppressed fast spin-echo images compared with the non-fat-suppressed spin-echo images. In part, the differences may relate to the imaging planes chosen, the location of the chondral injuries, and the different pulse sequences used. Characteristically, the subchondral edema was hemispheric or dome-shaped, centered directly over the cartilage defect (Fig. 3). The number of cases in which a defect was seen in the articular surface without associated subchondral edema was highest for the spin-echo T2-weighted images (Table 1). Complete agreement between the observers was highest for the spin-echo (83%; κ = 0.71) and fast spin-echo images (86%; κ = 0.71). Concordance was lower for the STIR images (72%; κ = 0.32).

When a final diagnosis was made using the information from all the pulse sequences combined, observer 1 identified subchondral edema associated with 15 of the lesions (83%) and observer 2 identified 13 articular defects (72%) with associated subchondral edema (Table 2). Despite being told which surface showed a cartilage injury at arthroscopy, neither observer could identify one lesion of the lateral femoral condyle, even in retrospect. This defect was the smallest in the study, measuring 3 × 4 mm, and was not treated at arthroscopy because of its small size. Observer 2 also failed to see one trochlear lesion, which was identified by observer 1 (Fig. 4). We expected that the surface defects would be easy to see on the MR images, given that they were all of full thickness and that the observers were told which surface was involved. However, both observers noted that the actual defects were easily overlooked and that subchondral edema was often recognized first and was used as a guide to identify the overlying surface abnormality. Because of the study design, the observers did not record the presence of subchondral edema if it was not associated with a visible cartilage defect; thus, we cannot comment on the specificity of this finding.

The three chondral flap lesions showed a characteristic appearance on the MR images, with an articular surface crater containing an in situ chondral fragment, which was attached at one end to the adjacent normal cartilage (Fig. 5). Although there was subchondral edema in the underlying bone in all three patients, no edema was seen in the detached chondral fragment.

**Fig. 3.—28-year-old man who was injured playing recreational basketball.**

**A**, Sagittal fast inversion-recovery MR image (TR/TE, 3733/69; inversion time, 155 msec) shows well-defined full-thickness cartilage defect (black arrows) of medial femoral condyle with typical hemispheric area of subchondral edema centered over lesion. Note also intraarticular chondral body (white arrow) anterior relative to crater.

**B**, Coronal fast spin-echo MR image (TR/TEeff, 5050/96) obtained with fat suppression also shows defect and characteristic dome-shaped overlying subchondral edema (arrow). Lesion was treated by microfracture at arthroscopy. Medial meniscus was also torn at arthroscopy.
Review of the prospective radiologic interpretations showed that the cartilage surface was prospectively called abnormal in 14 of the 18 cases, although a specific diagnosis of chondral flap or chondral fracture was not specified in every case. In one lesion of the lateral femoral condyle, the differential diagnosis of early avascular necrosis was offered. Three of the four defects not prospectively diagnosed were visible retrospectively by both observers. In two of these cases, the lack of subchondral edema may have initially decreased the conspicuity of the lesion (Fig. 6). Additionally, three of the four knees containing prospectively missed lesions were examined using our older imaging protocol, which did not include sagittal STIR images.

Discussion

Chondral flaps and fractures (Figs. 1B and 1C) form an important subset of knee injuries. They usually result from a twisting injury or direct blow [1, 2, 5, 6, 14], although not all patients recall a specific episode of trauma [6]. In skeletally mature individuals, injuring forces preferentially propagate along the tidemark, a natural cleavage plane that separates the deepest calcified layer of cartilage and subchondral plate from the overlying nonmineralized cartilage layers [1, 5, 21]. The result is that most traumatic cartilage injuries involve a full-thickness chondral separation from the underlying bone [8]. The same mechanisms in adolescents may result in osteochondral fractures or disruption of an underlying osteochondritis dissecans lesion [8, 14]. In skeletally immature patients, a defined tidemark is not present, theoretically allowing forces traveling within the chondral layers to extend down into the underlying bone (Fig. 1D). Thus, although osteochondral injuries occur during childhood and early adolescence, pure chondral injuries rarely occur before early adulthood [4, 5, 8, 9, 21]; the youngest patient in our series was 18 years old. Additionally, unlike osteochondral injuries, chondral flaps and fractures are radiographically occult [3, 5, 14]. These traumatic lesions are also distinct from degenerative chondrosis (Fig. 1E). Traumatic lesions typically occur on the weight-bearing surfaces of the condyles and the craters have sharp vertical walls, whereas degenerative lesions usually begin on the posterior portions of the condyles, have shallow walls, and have an indistinct boundary with the surrounding uninvolved cartilage [4, 6–8, 20, 21].

The pain and swelling that occur in patients with chondral injuries mimic the symptoms of a torn meniscus, which is frequently the initial clinical diagnosis [4–6, 8, 14]. Chondral injuries may coexist with meniscal lesions [6, 14], as was the case in 56% of the patients in our series. The initial clinical diagnosis was a meniscal tear in 89%; a chondral injury was considered in only two of the 18 knees before MR imaging. This trend was not surprising because isolated cartilage injuries are difficult to diagnose clinically [2] and are relatively infrequent compared with meniscal tears [8, 21, 22]. Although cartilage in-

![Fig. 4.—29-year-old man with trochlear cartilage defect. Lesion was treated by microfracture.](A) Sagittal spin-echo MR image (TR/TE, 2333/75) shows cartilage defect (between arrows). This defect was seen only by observer 1.
(B) Subtle subchondral edema (arrow) on fast inversion-recovery MR image (2932/69; inversion time, 155 msec) is clue to overlying cartilage defect.
juries can be shown on conventional arthrography [14], arthroscopy is currently the preferred method of diagnosis [5, 7, 9, 14, 22].

Surgical treatment for chondral injuries is evolving. Older, nonspecific interventions such as joint lavage and débridement have produced disappointing long-term results, with either incomplete healing or production of fibrocartilage, which lacks many of the mechanical properties of hyaline cartilage and eventually degenerates [10, 15, 23]. Specific treatment of focal cartilage defects now involves drilling, abrasion, or microfracture to perforate the tidemark and subchondral plate, inducing bleeding into the defect from the subchondral bone [2, 4, 7, 14, 15]. This procedure is followed by a period of non-weight-bearing and continuous passive motion, which enhances the ability of the reparative tissue to differentiate into hyalinelike cartilage [24]. New therapies include application of various biologic grafts such as periosteal and perichondral autografts [10], osteochondral allografts [16, 17], osteochondral autografts [19], and autologous cartilage transplants [18]. Indications for these procedures and their associated outcomes are currently being investigated, but the more aggressive grafting and transplantation techniques

Fig. 5.—Cartilage flap lesion in 39-year-old man who fell from ladder. 
A, Sagittal spin-echo MR image (TR/TE, 2533/75) shows full-thickness defect with in situ chondral fragment (arrow) on weight-bearing surface of medial femoral condyle. 
B, Coronal fat-suppressed fast spin-echo MR image (4550/96) shows that fragment (arrow) remains attached laterally through intact bridge of cartilage (arrowhead). Compare with Figure 1B. Note edema is present within overlying subchondral bone but not in chondral fragment. At arthroscopy (not shown) flap was removed and subchondral bed was treated by microfracture technique.

Fig. 6.—Prospectively missed chondral defect in 29-year-old woman. 
A, Both observers retrospectively saw full-thickness cartilage defect in medial femoral condyle (arrow) on sagittal spin-echo MR image (TR/TE, 2150/75). 
B, Coronal fat-suppressed fast spin-echo MR image (4800/96) also shows articular surface defect (arrow). Neither observer saw overlying subchondral edema, which may have contributed to this lesion being overlooked prospectively.
MR Imaging of Chondral Injuries in the Knee

require significant preoperative planning [16–19], emphasizing the need for a reliable method of noninvasive diagnosis.

In our practice, we routinely use two-dimensional spin-echo, fat-suppressed fast spin-echo, and STIR imaging to reveal meniscal, ligamentous, and musculotendinous disorders in the knee. We found that we were able to retrospectively identify treatable chondral defects on these images. The cartilage injuries appeared as defects in the articular surface with vertical margins, usually sharply marginated from the adjacent normal cartilage, similar to their arthroscopic appearance [4, 6, 8]. Prospectively, even though most of the MR studies were requested to evaluate the knee for a potential meniscal tear, an articular cartilage abnormality was identified or suggested in 78% of the cases (14/18). This figure likely represents an overestimate of our prospective sensitivity because any abnormality noted in the articular surface was counted as positive; the radiologists who prospectively interpreted the MR studies did not, as a rule, try to distinguish traumatic chondral lesions from other disorders of the chondral surface. Speer et al. [21] studied the MR appearance of acute chondral injuries in the knee using conventional two-dimensional pulse sequences. Their sensitivity for detecting these lesions prospectively was 31% and retrospectively was 71%. However, Speer et al. did not use fat-suppression techniques to enhance the visualization of subchondral edema, which may have limited their ability to identify some of the lesions [25]. Although the prospective reports in our study were often not detailed enough to determine whether radiologists used subchondral edema as a clue in their evaluation of the chondral surfaces, we suspect that having worked with these sequences on a routine basis, the radiologists did use this information, either knowingly or unknowingly. This fact may in part explain the relatively high percentage of lesions found prospectively compared with the sensitivity reported by Speer et al. Additionally, our strict inclusion criteria—that all lesions had to be potentially treatable—may have biased the sample set to more obvious lesions than those included in prior studies.

In our study, subchondral edema was identified to be associated with chondral surface defects in 83% (observer 1) and 72% (observer 2) of the cases (Table 2). We postulate three possible mechanisms for the generation of this marrow edema: The injury to the subchondral bone can precede the articular cartilage injury, can occur at the same time as the cartilage injury, or can follow the cartilage injury. Support for the first possibility comes from animal studies of experimentally created chondral injuries that show injury to the subchondral trabeculae can precede injury to the overlying cartilage by several weeks [26–30]. Marrow edema shown on MR images is thought to reflect the initial injury to the subchondral bone in these cases [28].

Support for the second possibility is that the initial force responsible for the cartilage fracture produces a transient depression of the articular surface that is transmitted to the subchondral plate. In this instance, the subchondral marrow edema would represent a direct contusion, or true bone “bruise.” Support for the third hypothesis is that the initial insult produces a cartilage defect large enough to expose the underlying bone to direct compression against the opposing articular surface once joint loading recommences [10]. Of course, several of the mechanisms proposed may work in concert to produce the MR finding of subchondral edema.

Our study is limited by its retrospective design in which observers were told which compartment contained the chondral injury, so they could specifically direct their attention to the underlying bone. We expected it would be fairly easy to identify the surface defects, knowing their location. Thus, we were surprised when both observers noted that it was frequently the signal changes in the subchondral bone that were first recognized and that these subchondral bone changes often directed the observers’ attention to the surface defects in the overlying cartilage. We believe that a familiarity with the appearance of these lesions, especially the importance of subchondral edema beneath cartilage infractions, should increase the radiologist’s ability to detect these lesions prospectively. Interestingly, a recent study using fat-suppressed T2-weighted fast spin-echo sequences to evaluate articular cartilage illustrated two knees in which subchondral edema was associated with degenerative chondrosis [31]. The authors of that study did not indicate how frequently they saw subchondral bone changes. Nor did they comment on whether subchondral edema assisted in the search for surface defects, but we suspect that subchondral edema may be useful in identifying some degenerative cartilage lesions as well as traumatic cartilage injuries.

A second limitation of our study is the small number of total lesions, in part because we used very strict inclusion criteria to maintain a uniform patient group. All knees had to have normal findings on radiographs. Additionally, for each lesion the arthroscopy report had to state that the chondral defect was at least potentially treatable. We were hindered by the variable terminology used by the arthroscopists, which meant that some potential cases may have been excluded because the arthroscopy report was not sufficiently detailed to determine whether a given lesion was degenerative or traumatic. The small number of cases also reflects the relative rarity of treatable cartilage defects [5, 8, 22].

Despite their relative infrequency, we contend that cartilage flaps and fractures form an important subset of knee disorders. These injuries clinically can mimic meniscal tears and are radiographically occult. Specific operative interventions for chondral injury have recently been introduced and are currently undergoing clinical evaluation. On routine MR images, chondral injuries appear as sharply demarcated defects in the articular surface. Characteristic subchondral edema revealed on fat-suppressed or STIR images may alert the radiologist to the presence of a defect in the overlying chondral surface that may have been otherwise overlooked.

Acknowledgment

We thank Eric Jablonowski for artistic assistance with Figure 1.

References
Rubin et al.


