Jerrold H. Mink, MD • Teresa Levy, BA • John V. Crues III, MD

# Tears of the Anterior Cruciate Ligament and Menisci of the Knee: MR Imaging Evaluation[1]

**In 242 of 3,000 patients who underwent magnetic resonance (MR) imaging of the knee between September 1986 and August 1987, original MR imaging reports were compared with subsequent arthroscopic reports to determine the value of MR imaging in the evaluation of suspected meniscal and complete tears of the anterior cruciate ligament. The overall accuracy for the menisci was 93% (sensitivity, 95%; specificity, 91%) with a false-negative rate of 4.8%. For the anterior cruciate ligament the overall accuracy was 95%. T2-weighted sequences were associated with greater sensitivity, specificity, and accuracy than were T1 sequences; the false-negative rate was 0% in the T2-weighted group. MR imaging of the knee is an extremely accurate means for noninvasive assessment of the integrity of the menisci and anterior cruciate ligament, and the accuracy exceeds that usually reported for arthrography.**

**Index terms:** Ligaments, cruciate, 4526.4857 • Ligaments, injuries, 4526.4857 • Ligaments, MR studies, 452.1214 • Knee, injuries, 4524.4852, 4525.4852, 4526.4857 • Knee, MR studies, 452.1214

**Radiology 1988;** 167:769–774

In 1985, Reicher et al (1,2) proposed that magnetic resonance (MR) imaging might be a clinically useful tool in evaluating internal derangement of the knee. Since that time, various studies in small numbers of patients have confirmed the utility of MR in the assessment of a variety of abnormalities, including those of the menisci (3–10), the ligaments (3,5, 7–9,11), and the articular cartilage (5,12,13), osteonecrosis (5,14), fractures (15), bone marrow replacement (16,17), and arthritic disorders (18,19). The purpose of this communication is to describe a study in a large population validating the utility of MR imaging in the evaluation of the menisci and the anterior cruciate ligament and to discuss the impact of technical advances that have improved the accuracy of MR examination and have broadened the range of its diagnostic capabilities.

## MATERIALS AND METHODS

Between August 1985 and September 1987 we performed more than 3,000 MR imaging examinations of the knee with a 1.5-T imager (General Electric, Milwaukee).

The operative records of 242 patients who had undergone both MR imaging examination and arthroscopy between September 1986 and August 1987 were compared with the original MR imaging interpretations of the menisci and the anterior cruciate ligament. Previously resected menisci were excluded from the study, so that 459 menisci were evaluated. Arthroscopy was performed by 37 different orthopedists. The results were tabulated for the entire group.

To test the effect of surgical skill and experience on the false-positive and accuracy rate, we analyzed separately the statistics for a single knee subspecialist arthroscopist (33 menisci). To enlarge this population, so that the analysis would be more valid, we added the records from 39 additional menisci that are not included in the larger study population. Thus, a total of 72 menisci composed this parallel study. While the grading system for meniscal signal used by Crues et al (6) was used in all MR reports, grade 1 and grade 2 lesions were lumped together and scored as "not torn," while grade 3 lesions were scored as "torn." The surgeons of record did not use a standardized terminology for what constituted a tear versus degeneration; therefore, any definite structural alteration (excluding discoloration, excessive flounce, etc), regardless of the specific wording used in the operative report, was scored as torn.

A total of 21 of the 34 false-positive and false-negative examinations were rereviewed independently by two radiologists (J.H.M., J.V.C.). The falsely interpreted images were intermingled with other correctly read images in an attempt to eliminate bias, but it must be noted that not each and every MR image was reexamined. Nine of the 11 false-negative and 12 of the 23 false-positive examinations were available for rereview.

Since no MR grading system for the anterior cruciate ligament has been previously established, the anterior cruciate ligament was graded as normal if it could be seen extending intact from the femur to the tibia. The normal anterior cruciate ligament was usually depicted as either a solid continuous signal-less band or three or four separate fiber bundles (3). By externally rotating the knee 10°–15°, it was possible to view the anterior cruciate ligament on a single sagittal image 85%–90% of the time. Thickness of the ligament was not specifically evaluated (and has not, in our experience, appeared to be a characteristic of normality). While foci of increased signal were considered abnormal (in some instances representing partial tears), ligaments harboring such signal were not judged torn if any portion of the ligament was intact. Similarly, terms such as "attenuated" or "thin" as used in the operative report were ignored if the orthopedist stated the ligament was intact.

During the 2 years, three different receive coils were used. However, a dedicated wraparound extremity coil (General Electric) with both send and receive properties, the latest coil, was used to examine 70% of the patients in this study.

The imaging protocol underwent progressive evolution (3), with T1- and T2-

[1] From the Department of Diagnostic Radiology, Cedars-Sinai Medical Center, 8700 Beverly Blvd, Los Angeles, CA 90048. From the 1987 RSNA annual meeting. Received December 1, 1987; revision requested January 5, 1988; revision received February 2; accepted February 23. **Address reprint requests to** J.H.M.

weighted sequences used in various combinations. Of the 242 knees analyzed in this report, 89 were examined with intermediate and T2-weighted (2,000/20, 80) (repetition time [TR] msec/echo time [TE] msec) sagittal sequences, and 153 were examined with T1-weighted (800/20) sagittal sequences. When the dedicated extremity coil was used the coronal images were obtained with a 256 × 128 matrix, 16-cm field of view, one excitation, and interleaved 5-mm-thick sections. In the sagittal plane, these technical factors were identical except that a 5-mm section thickness with no intersection gap was used. All patients were examined in the supine position with the leg externally rotated 10°–15° (most patients tend to externally rotate the knee properly when they assume a comfortable supine position) and in full extension, a position that optimizes evaluation of the anterior cruciate ligament.

**Table 1**
**Results of MR Imaging of the Menisci**

| Meniscus | Sensitivity (%) | Specificity (%) | False-Positive Results (%) | False-Negative Results (%) | Accuracy (%) |
|---|---|---|---|---|---|
| Medial | 97 | 89 | 7 | 4.7 | 94 |
| Lateral | 92 | 91 | 14 | 4.9 | 92 |
| Total | 95 | 91 | 10 | 4.8 | 93 |

**Table 2**
**Results of MR Imaging of the Anterior Cruciate Ligament**

| Sequence | Sensitivity (%) | Specificity (%) | Accuracy (%) |
|---|---|---|---|
| T1-weighted | 85 | 95 | 94 |
| T2-weighted | 100 | 96 | 97 |
| Total | 92 | 95 | 95 |

## RESULTS

Of the group of 459 surgically correlated menisci, there were 207 true-positive, 218 true-negative, 23 false-positive, and 11 false-negative meniscal correlations. The 218 tears occurred in 173 patients (45 patients had both medial and lateral tears in the same knee); 72% of patients who underwent surgery had a meniscal tear. Overall, the sensitivity for the detection of meniscal tears was 95%, with a specificity of 91% and an accuracy of 93% (Table 1). The false-positive rate was 10%, and the false-negative rate was 4.8%. Accuracy rates for individual orthopedists ranged from 87% to 95%; false-positive rates varied from 6% to 16%, and false-negative rates from 2% to 9%. The accuracy for the knee subspecialist was 95% (25 true-positive findings; 44 true-negative findings; two false-positive findings; one false-negative finding; sensitivity, 96%; specificity, 95%).

Forty-four percent of all errors involved evaluation of the free edge (five of 11 false-negative and ten of 23 false-positive findings with MR). Images for nine of the 11 MR examinations with false-negative results and 12 of 23 with false-positive results were available for rereview by two radiologists (J.H.M., J.V.C.). In only one false-positive and one false-negative case did both correctly revise their readings. Of the 11 MR imaging examinations with false-negative results, five of the tears were parrot-beak tears (four lateral, one medial), two were bucket-handle tears, and four were nondescript. Two of the four parrot-beak tears were described as "small, minute tears," and two of the miscellaneous tears were partial-thickness tears.

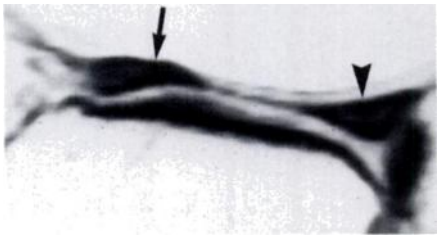
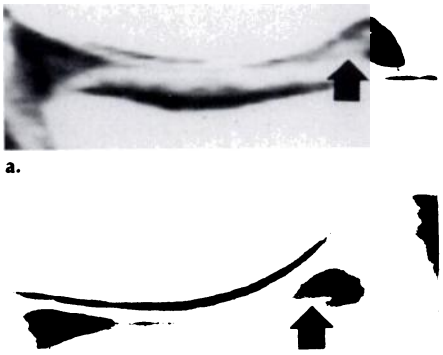


**Figure 1.** Sagittal MR image (2,000/20) of meniscal horns: false-negative findings. Magnified, high-contrast image demonstrates seemingly normal anterior (arrow) and posterior (arrowhead) lateral meniscal horns. A bucket-handle tear of the meniscus was found at surgery 2 weeks later.



a.

b.

**Figure 2.** Sagittal MR images (2,000/20): false-positive findings. Magnified, deliberately high-contrast images in two different patients reveal a grade 3 signal (arrow) extending along the undersurface and tips of both menisci. The lesion in **a** represented a small flap tear, but no abnormality was found in **b.**

For MR imaging of the anterior cruciate ligament there were 36 true-positive, 193 true-negative, ten false-positive, and three false-negative findings. The overall results were subdivided into those imaged with T1-weighted and those imaged with T2-weighted sequences; results of this analysis are shown in Table 2. The overall accuracy rate for detection of complete tears of the anterior cruciate ligament was 95%. The most striking difference between the T1- and T2-weighted studies is the apparently improved sensitivity of the T2-weighted examination in the detection of tears of the anterior cruciate ligament (100% vs 85%).

## DISCUSSION

There has been great excitement about noninvasive evaluation of the menisci and ligaments of the knee with MR imaging. Reports of small series from various institutions have documented a high degree of accuracy for a broad spectrum of abnormalities (1–19). This correlated study of 459 menisci is, to our knowledge, the largest series yet and provides significant support of the clinical value of MR imaging of the knee. The overall accuracy of 93% approximates that in several smaller series (6–8,12,15) in which 1.5-T imagers were used.

In an attempt to identify and explain our interpretive errors, we undertook a critical review of our false-positive and false-negative findings at MR imaging examination. Of the 11 tears in which there were false-negative MR results, one was thought to be so insignificant at arthroscopy as to not warrant any type of intraarticular therapy. Four of the tears were debrided, and only six required a partial meniscectomy (Fig 1). The false-negative rate in this study is 4.8%, which compares quite favorably with the false-negative

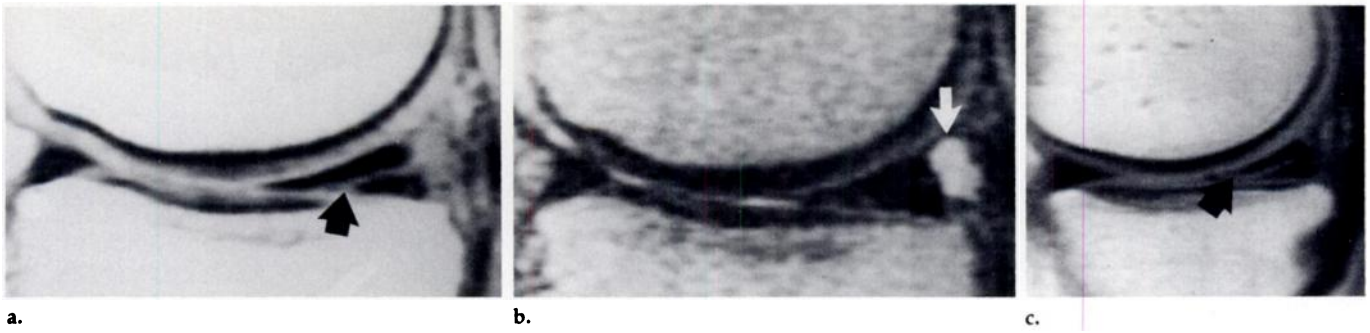



**Figure 3.** Meniscal tears. **(a)** Sagittal image (2,000/20) clearly demonstrates a medial meniscal tear (arrow), a finding confirmed at surgery. **(b)** Tear through the substance of the meniscus is extremely difficult or impossible to appreciate on the second echo image (2,000/80). Posterior horn, with fluid behind the meniscus (arrow), was found to also be partially detached. **(c, d)** In a different patient, intermediate (2,000/20) **(c)** and T2-weighted (2,000/80) **(d)** sagittal images both demonstrate a surgically proved tear (arrow). The lesion is as intense as synovial fluid on both images.

rates of 2%–13% for arthrography and 5%–10% for arthroscopy (8,20–23). Thus, the risk of failure to detect a *clinically significant* tear with MR imaging is quite low.

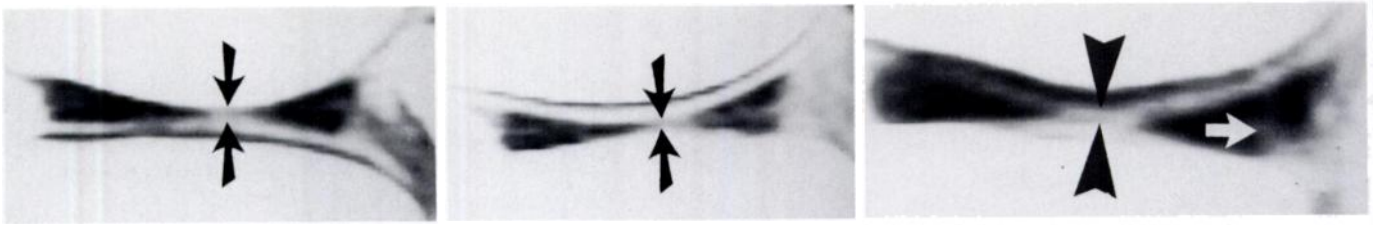
The occurrence of false-positive findings at MR imaging (Fig 2) (as judged with arthroscopy) has been noted before (3,5,7) and has been a source of frustration for radiologists and complaints by clinicians. There are at least two explanations for this apparent discrepancy between findings at MR imaging and surgery, the operator dependence of arthroscopy and the presence of intrasubstance tears.

Arthroscopy is a highly operator-dependent procedure that requires great manual dexterity. Casscells (24) has noted that "some surgeons learn arthroscopy slowly or not at all and some are not very capable in this [diagnostic arthroscopy] respect." Arthroscopy has been reported to have an accuracy of 69%–98%, depending on the experience of the examiner and the type of location of the tear; false-negative arthroscopic results are well documented (8,20–22,25). Nonetheless, surgeons generally regard arthroscopy as a standard of reference. Our current report is based on the operative findings from 37 orthopedists of varying levels of experience with arthroscopy. False-positive MR imaging rates varied from 6% to 16% among the 37 orthopedists, but the false-positive rate of the knee subspecialist arthroscopist was only 6%. In 12 of 23 cases with false-positive findings at MR imaging the tear was in the posterior horns (eight medial, four lateral). In five studies (including this one) (5–7,10), a total of 47 false-positive results with MR imaging have been reported; 33 of the "tears" were in the posterior horns (70%). Thus, false-positive MR imaging findings are frequently reported in the area acknowledged to be the most difficult for the clinician to examine (20–22,25). It appears that the false-positive MR imaging rate is the inverse of the false-negative arthroscopy rate, which, in turn, is directly a function of surgical skill and experience.

Stoller et al (26) recently examined the histologic correlation of the different grades of MR signal. They found instances in which definite grade 3 signal intensity was seen in MR images of menisci that, when removed from a cadaver, showed no macroscopic tear. Histologically, however, definite separation of fibrocartilage (meniscal tear) could be demonstrated. The existence of intrasubstance (closed) tears is well known and provides the basis for systematic, careful, and persistent meniscal probing, which may reveal lesions not visible at gross examination (20–23,25). Burk et al (5) reported an MR imaging grade 3, arthroscopically negative lesion that, on reoperation for persistent symptoms, demonstrated a bucket-handle tear. Perhaps an intrasubstance tear progressed to a frank tear.

Because of operator error, limitations of the technique of arthroscopy, and the existence of intrasubstance tears, false-positive findings at MR imaging examinations are likely to continue to be reported (Fig 2). A clinician in possession of an MR report indicating the existence of a tear, especially in the posterior horn of the medial meniscus, must extensively probe and explore the meniscus before assigning the discrepancy to an "overreading" of MR images. (Such persistence revealed a tear in 14 cases that, judging from the statement of the arthroscopist in his report, may well have been overlooked by him were it not for the MR imaging findings.) Even if no tear is found at surgery, the orthopedist also may wish to advise his patient of the possible existence of an intrasubstance tear accounting for symptoms (3). Whether or not intrasubstance tears inexorably extend to an articular surface is unknown.

It has been our unequivocal impression, as well as that of Stoller et al (26,27) and Mink et al (3), that most meniscal tears are best appreciated on T1- or intermediate-weighted (2,000/20) rather than T2-weighted sequences (Fig 3). Mink et al (3) postulated that T1 shortening could be secondary to water adsorption on macromolecules, which would thereby increase the local spin-density. The decrease in translational motion would lead to shortening of the T2 (resulting in decreased intensity on T2-weighted images). We randomly selected 21 cases with true-positive results and seven with false-positive results that had been performed with our T2-weighted sequence (all of the false-positive studies were positive even on rereview). Fourteen of the 21 true tears were very poorly seen on the second echo images (2,000/20, 80) (Fig 3). In none of the seven false-positive images, however, were the tears seen as well on the second echo image as on the first, and, in fact, four were not seen at all on the sec-



a. b. c.

d.

**Figure 4.** Suspected parrot-beak tears. **(a, b)** On sagittal images (2,000/20) in two different patients grade 3 signal is present at the expected free edge of the lateral meniscus (arrows). Lesion in **b** was a small edge tear, but no abnormality was found in **a.** Partial volume effect contributes to the confusion. **(c)** In a third patient, area of increased intensity (arrowheads) on sagittal image near the free edge and between the tips of the anterior and posterior horns of lateral meniscus could be a small radial (parrot-beak) tear, or merely partial volume effect. A high-contrast, magnified image (2,000/20) is used to best demonstrate the finding. A small separate posterior horn tear (arrow) is present. **(d)** Coronal image (800/20) in the same patient as in **c** confirms that there is, in fact, signal in the central tip of the midzone of the meniscus (arrowheads). A small parrot-beak tear was resected.

ond echo. Decreased signal-to-noise ratio (S/N) may contribute to poor delineation of some tears on T2-weighted images, but since some tears remain hyperintense S/N is not the only factor. High-intensity signal on a second echo image (occurring in seven of our true-positive images of tears) may prove to be specific for a tear since none of the false-positive MR imaging examinations had this quality. Most of our surgically confirmed tears did not increase in signal intensity on a second echo, and, therefore, contrary to the beliefs of Li et al (7), we find increased signal intensity on a T2-weighted image to be a sign of low sensitivity of a meniscal tear.

While many radial and parrot-beak (edge) tears were accurately identified preoperatively, incorrect evaluation of the free meniscal edge was by far the greatest single source of errors in this study (44% of all errors). Five of the 11 false-negative and ten of 23 false-positive interpretations of MR images involved the free edge (Fig 4). Unquestionably, one factor that has contributed to both false-positive and false-negative errors is partial volume effect, which is in part determined by the relationship of the free meniscal edge to the center of the 5-mm-thick section. Correlation with findings on high-resolution coronal images (Fig 4) and perhaps smaller section thickness should theoretically reduce this problem. Of the ten false-positive findings of edge tears in this study, seven were part of examinations done without benefit of high-resolution coronal sequences.

Our accuracy for evaluation with MR imaging of complete tears of the anterior cruciate ligament (94%) is equivalent to the best arthrographic results reported (95%) (28) and exceeds the more common experience of 60%–85% (20,25,29). The criteria we established for the integrity of the anterior cruciate ligament may have contributed to the high degree of accuracy. Small foci of abnormal signal, if associated with an intact ligament, were ignored. No attempt was made to assess the functional status of the ligament; only the anatomic status was assessed. The routine use of T2-weighted images appeared to improve sensitivity (and was associated with a false-negative rate of zero) when compared with the sensitivity in the subgroup of patients in whom only T1-weighted images were obtained. Sample sizes are too small to achieve statistical significance. Without question, however, our confidence in evaluating the anterior cruciate ligament was improved by the use of T2 weighting (Fig 5) (Table 2).

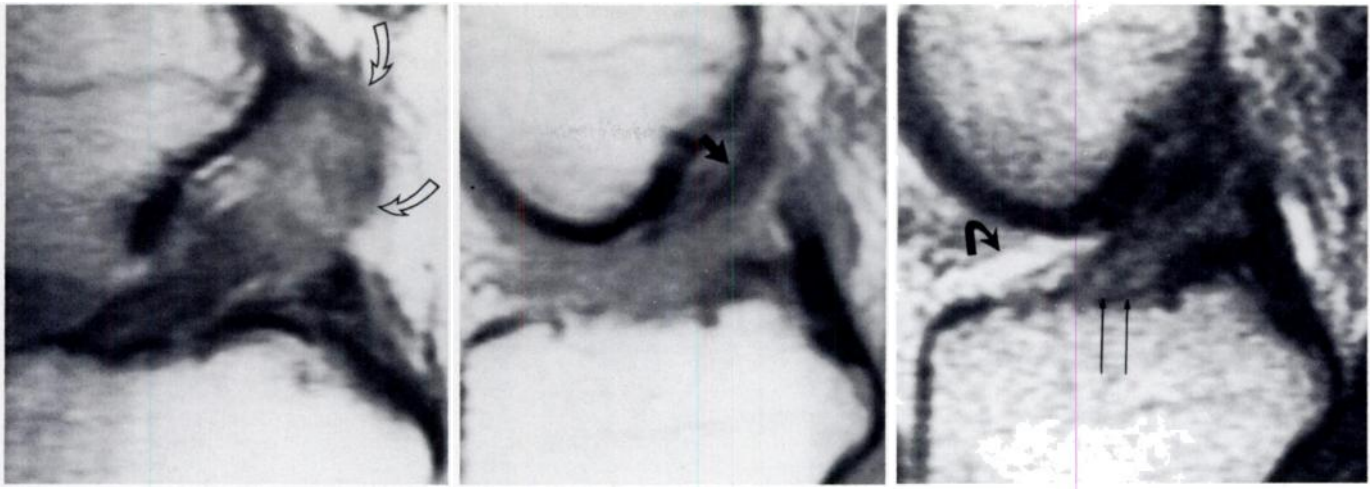
There are several signs that may be helpful in evaluating the anterior cruciate ligament. Acute angulation of the proximal posterior cruciate ligament is always abnormal. If there is no intrinsic abnormality of the posterior cruciate ligament, "buckling" in the clinical setting of acute trauma is overwhelmingly indicative of a tear of the anterior cruciate ligament (3). The position of the knee in our coil during MR imaging examination and the relaxed state assumed by our patients apparently predispose to an anterior drawer maneuver, allowing the tibia to shift forward and pull the distal posterior cruciate ligament with it; the proximal end then buckles.

The distal end of the anterior cruciate ligament is usually better delimited than the proximal end due to partial volume averaging of the proximal ligament with the sagittally oriented medial face of the lateral femoral condyle. A normal distal and mid-anterior cruciate ligament, coursing in the proper direction and unassociated with a soft-tissue mass, is usually normal even if the proximal end is not optimally seen (again, coronal images may be helpful). A true mass (not an apparent mass resulting from partial volume averaging of the lateral femoral condyle) at the proximal end, associated with abnormal signal, however, indicates the presence of a tear.

MR imaging has undergone incredibly rapid evolution, and technical advances are continually occurring. New coil geometry and imager software upgrades have resulted in frequent protocol changes, although since March 1987 our technique has not changed. A number of technical advances have improved the accuracy, ease, and speed of the examination, and their impact deserves particular mention.

The availability of a dedicated wraparound extremity coil with send-receive capability has had the single greatest impact on image quality, speed of examination (permitting single-excitation examinations), and the ability to obtain high-resolution coronal images. Previously, coronal images were little more than localizers, but now they can reduce the confusion due to partial volume effect occurring at the free edge of the mid-zone of either meniscus. Coronal images are most helpful in locating the "handle" from a bucket-handle tear (Fig 6), identifying suspected loose bodies (Fig 7), and evaluating the collateral ligaments and segments of the articular cartilage.

The capability of rapid acquisition of high-quality T2-weighted images is, in a sense, a technical achieve-



b. c. d.

a.

**Figure 5.** Anterior cruciate ligament. **(a)** Occasionally, a pseudomass (solid arrows) is present at the proximal end of the anterior cruciate ligament on sagittal images (2,000/20). The "mass" represents the result of partial volume effect of the lateral femoral condyle (curved open arrow) with the anterior cruciate ligament. The ligament was found to be normal at surgery. **(b)** On a sagittal image in another patient, a true mass (arrows), representing a torn anterior cruciate ligament, is seen. **(c, d)** In sagittal images in a patient with a normal anterior cruciate ligament at surgery, the proximal part of the ligament (arrow) appears normal, but the distal segment has an appearance quite like that of fluid (2,000/20) **(c)**, but on the second-echo image (2,000/80) **(d)** the fluid (curved arrow) becomes hyperintense and the multiple fibers of the normal distal anterior cruciate ligament (straight arrows) are readily visible.

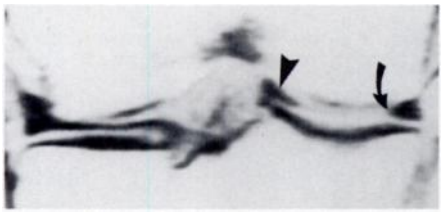
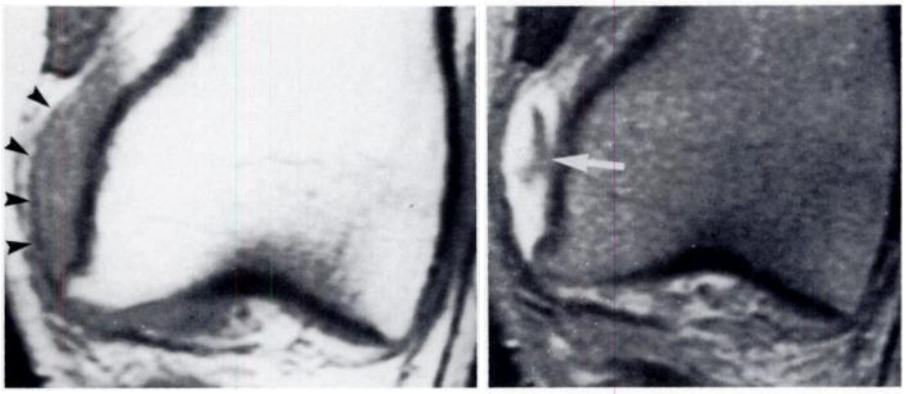


**Figure 6.** Bucket-handle tear. On coronal image, the mid-zone of the medial meniscus (arrow) may be slightly blunted, but it otherwise appears normal. Displaced fragment (arrowhead) is seen in the intercondylar notch, supporting the diagnosis of a bucket-handle tear. The fragment could not be confidently identified on sagittal images (not shown).



a. b.

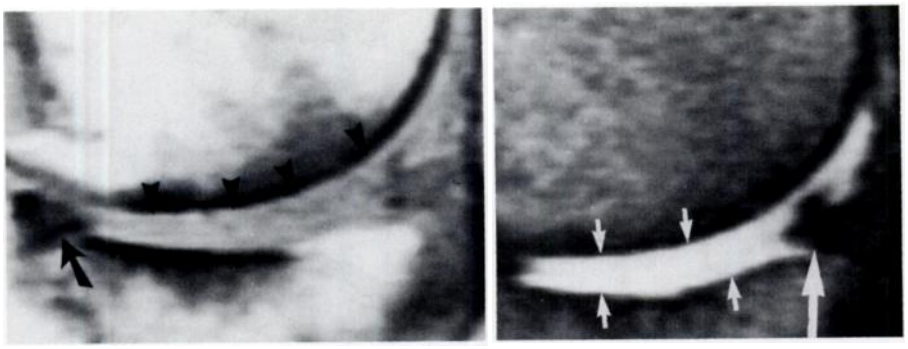
**Figure 7.** Loose body. On coronal image, chondral fragment (arrow) is easily seen in the medial reflection of the suprapatellar bursa (arrowheads) on a T2-weighted sequence (2,000/80) **(b)** but was appreciated on the T1-weighted sequence (800/80) **(a)** only in retrospect.

ment. The routine use of T2-weighted imaging has improved the accuracy of diagnosis of tears of the anterior cruciate ligament (Table 2), the existence of torn meniscal remnants (Fig 8), intra- and extraarticular fluid, meniscocapsular separation (Fig 3) (3), loose bodies (Fig 7), chondromalacia of the patella (19), osteochondritis dessicans or osteonecrosis (30), and collateral ligament tears (3,7,11). MR imaging of the knee is a rapid, safe, and highly accurate means of noninvasively assessing the status of the menisci and the anterior cruciate ligament. ■

**Acknowledgments:** The authors thank Joe Fraire, Amy Liethen, Mark Tournie, Alicia Vasquez, Kim Weber, and Iris Kelly-Dokubo for their technical assistance, and Elaine Mudrick, Francisco Chanes, and the Audio-Visual Department of Cedars-Sinai Medical Center for their assistance in the preparation of this manuscript.

## References

1. Reicher MA, Bassett LW, Gold RH. High-resolution magnetic resonance imaging of the knee joint: pathologic correlations. AJR 1985; 145:903–909.
2. Reicher MA, Rauschning W, Gold RH, Bassett LW, Lufkin RB, Glen W. High-resolution magnetic resonance imaging of the knee joint: normal anatomy. AJR 1985; 145:895–902.
3. Mink JH, Reicher MA, Crues JV III, eds. Magnetic resonance imaging of the knee. New York: Raven, 1987.
4. Beltran J, Noto AM, Mosure JC, Weiss KL, Zuelzer W, Christoforidis AJ. The knee: surface-coil MR imaging at 1.5 T. Radiology 1986; 159:747–751.
5. Burk DL, Kanal E, Brunberg JA, Johnstone GF, Swensen HE, Wolf GL. 1.5 T surface-coil MRI of the knee. AJR 1986; 147:293–300.
6. Crues JC, Mink J, Levy TL, Lotysch M, Stoller DW. Meniscal tears of the knee: accuracy of MR imaging of the knee: first 144 cases. Radiology 1987; 164:445–448.
7. Li DKB, Adams ME, McConkey JP. Magnetic resonance imaging of the ligaments and menisci of the knee. Radiol Clin North Am 1986; 24:209–229.
8. Mandelbaum BR, Finerman GAM, Reicher MA, et al. Magnetic resonance imaging as a tool for evaluation of traumatic knee injuries. Am J Sports Med 1986; 14:361–370.
9. Reicher MA, Hartzman S, Bassett LW, Mandelbaum B, Duckwiler G, Gold RH. MR imaging of the knee. I. Traumatic dis-



a. b.

**Figure 8.** Diffusely torn meniscal remnant. **(a)** On sagittal high-contrast T1-weighted image (800/20) on the medial side of the joint in a patient in whom cartilage had been removed homogeneous signal (arrowheads) is demonstrated between the femur and tibia. Anterior horn has signal within it (arrow), but it is difficult to be certain how much, if any, posterior horn is present. Low-intensity signal in the femur presumably represents degenerative sclerosis. **(b)** T2-weighted sagittal image (2,000/80) with hyperintense joint fluid demonstrates a markedly deformed posterior horn remnant (large arrow), as well as absence of the articular cartilages (small arrows). A diffusely torn meniscal remnant and severe chondromalacia were found at surgery.


orders. Radiology 1987; 162:547–553.

10. Reicher MA, Hartzman S, Duckwiler GR, Bassett LW, Anderson IJ, Gold RH. Meniscal injuries: detection using MR imaging. Radiology 1986; 159:753–757.
11. Turner DA, Prodromos CC, Petasnick JP, Clark JW. Acute injury of the ligaments of the knee: magnetic resonance evaluation. Radiology 1985; 154:717–722.
12. Gylys-Morin VM, Hajek PC, Sartoris DJ, Resnick D. Articular cartilage defects: detectability in cadaver knees with MR. AJR 1987; 148:1153–1157.
13. Hajek PC, Baker LL, Sartoris DJ, Neumann CH, Resnick D. MR arthrography: an anatomic-pathologic investigation. Radiology 1987; 163:141–147.
14. Pollack M, Dalinka M, Kressel H, Lotke P, Spritzer C. MRI in the evaluation of suspected osteonecrosis of the knee. Skeletal Radiol 1987; 16:121–127.
15. Stafford SA, Rosenthal DI, Gebhardt MC, Brady TJ, Scott JA. MRI in stress fracture. AJR 1986; 147:553–556.
16. Hudson TM, Hamlin DJ, Enneking WF, Petterson H. Magnetic resonance imaging of bone and soft tissue tumors: early experience in 31 patients compared with computed tomography. Skeletal Radiol 1985; 13:135–146.
17. Daffner RH, Lupetin AR, Dash N, Deeb ZL, Sefczek RJ, Shapiro RL. MRI in the detection of malignant infiltration of bone marrow. AJR 1987; 146:353–358.
18. Senac M, Deutsch D, Bernstein B, Crues J, Stoller D, Mink J. MR imaging in juvenile rheumatoid arthritis. AJR 1988; 150:873–880.
19. Yulish BS, Montanez J, Goodfellow DB, Bryan PJ, Mulopulos GP, Modic MT. Chondromalacia patellae: assessment with MR imaging. Radiology 1987; 164:763–766.
20. Levinsohn EM, Baker BE. Prearthrotomy diagnostic evaluation of the knee: review of 100 cases diagnosed by arthrography and arthroscopy. AJR 1980; 134:107–111.
21. Gillies H, Seligson D. Precision in the diagnosis of meniscal lesions: a comparison of clinical evaluation, arthrography, and arthroscopy. J Bone Joint Surg [Am] 1979; 61:343–346.
22. Ireland J, Trickey EL, Stoker DJ. Arthroscopy and arthrography of the knee: a critical review. J Bone Joint Surg [Br] 1980; 62: 3–6.
23. Stoker DJ, Renton P, Fulton A. The value of arthrography in the management of internal derangements of the knee: the first 1000 are the worst. Clin Radiol 1981; 32: 557–566.
24. Casscells SW. The role of arthroscopy in the armamentarium of the orthopedic surgeon. In: McGinty JB, ed. Techniques in orthopedics. Rockville, Md: Aspen, 1985.
25. Selesnick FH, Noble HB, Bachman DC, Steinberg FL. Internal derangement of the knee: diagnosis by arthrography, arthroscopy, and arthrotomy. Clin Orthop 1985; 196:26–30.
26. Stoller DW, Martin C, Crues JV, Kaplan L, Mink JH. Meniscal tears: pathologic correlation with MR imaging. Radiology 1987; 163:731–735.
27. Stoller D. MRI of the knee. In: Brady T, ed. Clinical applications of MRI. Philadelphia: Saunders (in press).
28. Pavlov H, Warren RF, Sherman MF, Cayea PD. The accuracy of double-contrast arthrographic evaluation of the anterior cruciate ligament. J Bone Joint Surg [Am] 1983; 65:175–183.
29. Thijn CJP. Accuracy of double-contrast arthrography and arthoscopy of the knee joint. Skeletal Radiol 1982; 8:187–192.
30. Mitchell DG, Rao VM, Dalinka MK, et al. Femoral head avascular necrosis: correlation of MR imaging, radiographic staging, radionuclide imaging, and clinical findings. Radiology 1987; 162:709–715.