Can MR Imaging Effectively Replace Diagnostic Arthroscopy?1

A study was performed to determine whether magnetic resonance (MR) imaging is cost-effective and reduces the need for diagnostic arthroscopy of the knee. During a 9-month period, 103 consecutive patients with knee injury that justified diagnostic arthroscopy underwent MR imaging. The MR images were interpreted by means of consensus of three radiologists and reviewed with the referring sports medicine orthopedists. After the examination, 44 patients (42.7%) underwent immediate arthroscopy. The 59 other patients (57.3%) did not undergo arthroscopy; follow-up was performed in 55 of these 59 patients (93%) at a mean of 22 months. The outcome was successful in 49 of 55 patients (89%); 40 patients had normal function and no limitation in activity, six patients with chronic injury of the anterior cruciate ligament underwent reconstruction, and three patients underwent arthroscopy with negative findings. Without the use of MR imaging, all patients in this study would have undergone diagnostic arthroscopy. Because of the diagnoses based on MR images, 53 patients (51.4%) avoided a potentially unnecessary diagnostic arthroscopy, and, as a result, the net savings was $103,700 in the 103 patients.

The clinical history and findings at physical examination in patients with abnormalities of the knee are known to be nonspecific in the determination of the cause of internal derangement. Physical examination of the knee was evaluated in a recent study of 161 patients with knee pain of at least 1 year duration (1). The predictive value of five common clinical tests (McMurray, flexion pinch, Apley grind, joint line tenderness, and extension block) for detection of meniscal tears was evaluated in a prospective fashion and compared with arthroscopic findings. None of the clinical tests were predictive for the presence of meniscal tears; this finding indicates that the clinical examination has considerable limitations whenever it is used to confirm the presence of meniscal lesions in the knee (1).

In patients in whom the diagnosis is uncertain, physicians must therefore turn to other diagnostic modalities to select the appropriate treatment. Arthrography has been shown to be highly accurate; however, it is invasive, technically demanding, necessitates exposure to ionizing radiation, and is limited in evaluation of structures external to the capsule (2-5). Because of these and other factors, arthroscopy has become the diagnostic procedure of choice (6).

Although diagnostic arthroscopy is expensive and invasive, proponents point to its accuracy and to the surgeon's ability to diagnose and treat abnormality with a single procedure (7). Unfortunately, diagnostic arthroscopy sometimes reveals no abnormality or only minor, possibly nonpathologic lesions such as plicae or chondromalacia patellae (8). Thus, patients may be subjected to an unnecessary surgical procedure with its associated risks and potential morbidity.

Alternatively, magnetic resonance (MR) imaging is noninvasive, and multiple studies have shown that it has high sensitivity and specificity, particularly for meniscal injury (9-13). Furthermore, MR imaging enables evaluation of extracapsular tissues and may enable distinction between patients without internal derangements and those who would benefit from therapeutic arthroscopy (9,14,15).

The success of MR imaging can be judged by two criteria: patient outcome and cost-effectiveness. If some patients avoid arthroscopy, then MR imaging may be beneficial. Furthermore, if the cost of diagnostic arthroscopy is avoided in a significant number of patients, then MR imaging in all patients may also save money (ie, it may be cost-effective). The purpose of this study was to determine whether MR imaging reduced the number of diagnostic arthroscopies necessary in patients with knee injury and whether MR imaging performed in all patients with suspected internal derangement was cost-effective compared with diagnostic arthroscopy in diagnosis of internal derangement of the knee.

PATIENTS AND METHODS

From March 1989 to December 1989, 103 patients (61 male patients and 42 female patients) aged 11-72 years (mean age, 31 years) underwent consecutive examination at the sports medicine center of our institution. All affected knees were evaluated by one of two senior specialists in orthopedic sports medicine (J.K.L., P.J.) with particular attention to the range of motion; findings at examination for effusion and at the McMurray and flexion pinch tests; and the pivot shift sign, joint-line tenderness, and quadriceps atrophy. All patients with findings sufficient to justify diagnostic arthroscopy and compatible with the diagnosis of internal knee de-

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Abbreviations: ACL = anterior cruciate ligament, FOV = field of view, SE = spin echo.
1. Figures 1, 2. (1) Flow chart of outcome in all patients (n = 103) enrolled in the study. Four patients were lost to follow-up. In Figures 1-3, NL = normal, *= success, f = failure. (2) Flow chart of outcome in all patients enrolled in the study who had symptoms that lasted 6 months or less. One patient was lost to follow-up.

rangement were enrolled in the study. The criteria for inclusion in the study were the following: persistent knee pain, recent knee effusions, repeated episodes of giving-way, presence of the McMurray sign, positive results of the flexion pinch test, or acute trauma. Patients with persistent knee pain complained of pain, swelling, locking, or giving-way (16,17). At this center, patients with persistent symptoms undergo diagnostic arthroscopy if they meet two conditions: The diagnosis cannot be accurately and reproducibly confirmed with other means and there is failure to respond to 6 weeks of directed physical therapy and other nonsurgical treatment.

In patients with symptoms that had lasted less than 6 months, the injury was classified as acute; in patients with symptoms that had lasted longer than six months, the injury was classified as chronic. The mean duration of symptoms was 2.0 months (range, 3–6 months) in the group with acute injury and 2.3 years (range, 6 months to 30 years) in the group with chronic injury. Rather than undergo diagnostic arthroscopic, patients who met the criteria described herein were scheduled for MR imaging of the knee. Before the MR examination, the orthopedic surgeons completed a questionnaire, indicating the area of suspected abnormality, and confirmed that arthroscopy was planned. Only patients who met one of the criteria for arthroscopy and in whom arthroscopy would have been otherwise performed were enrolled in the study. Patients with locked knees were excluded from the study and underwent therapeutic arthroscopy without MR examination (18).

MR imaging was performed by means of a 1.5-T imager (Signa; GE Medical Systems, Milwaukee) with a transmit-receive coil. The first series of images consisted of axial T2-weighted images obtained with a spin-echo (SE) sequence (repetition time msec/echo time msec = 1,500/20, 80), 16-cm field of view (FOV), 128 x 128 matrix, one signal average, and 5-mm section thickness with a gap of 2.5 mm. An axial T2-weighted image was used as a localizer to evaluate patellar cartilage, tears of the medial or lateral patellar retinaculum, and potential Baker cysts. The second series of images consisted of sagittal T1-weighted images (SE 600–800/13–20) obtained with a 14-cm FOV, 192 x 256 matrix, one signal average, and contiguous sections 3 mm thick. The third series of images consisted of coronal intermediate and T2-weighted images (SE 1,600, 2,300/20, 80) obtained with a 14-cm FOV, 192 x 256 matrix, one signal average, and 3-mm section thickness with a gap of 0.3 mm.

The MR images were interpreted by means of consensus of three radiologists experienced in MR imaging and were subsequently reviewed with the referring sports medicine orthopedists (J.K.L., P.J.). Meniscal changes and tears were classified, according to the system of Crues et al (9), in three grades of signal intensity: Grade 1 was defined as an area of globular intrameniscal signal intensity that did not contact the articular margin; grade 2, an area of primarily linear signal intensity that did not contact the articular margin; and grade 3, an area of linear or globular signal intensity that contacted the articular margin. On the basis of the findings on the MR images, patients underwent either therapeutic arthroscopy or continued nonsurgical treatment.

Patients with a grade 3 change, a loose body, or a meniscal cyst underwent therapeutic arthroscopy. Patients with normal findings on MR images or a diagnosis of an isolated ligament tear, intrasubstance meniscal changes, or a Baker cyst on MR images underwent continued nonsurgical treatment and did not undergo therapeutic arthroscopy. At this university, patients with an isolated tear of the anterior cruciate ligament (ACL) generally undergo acute surgical repair only in the presence of an associated meniscal tear. These patients undergo meniscal repair, if possible, along with ACL reconstruction (19).

Patients who underwent continued nonsurgical treatment were evaluated at a minimum of 17 months after MR imaging by means of a standardized 18-item questionnaire or telephone interview. The questions were designed to assess the patients’ functional abilities and limitations—level of athletic activity and the presence of pain, swelling, and instability of the knee—and a subjective assessment of their return to normal activities.

Outcome was classified a failure if the patient underwent diagnostic arthroscopy with positive findings or had persistent complaints that limited activity. Outcome was considered a success if the patient (a) did not undergo subsequent diagnostic arthroscopy with positive findings and was functioning normally without marked limitation in activity or (b) underwent reconstructive surgery for chronic instability due to a tear of the ACL diagnosed with MR imaging or underwent subsequent diagnostic arthroscopy with negative findings.

Cost-effectiveness was based on the estimated cost of $1,000 per MR examination of the knee in all patients and a savings of $3,900 in each patient in whom diagnostic arthroscopy was not performed. The cost of the MR examination of the knee was based on a facility fee of $700 and a professional fee of $300. The cost of arthroscopy was composed of the fees of the surgeon ($1,400), facility ($500), and anesthesiologist ($1,000). The cost-effectiveness in all patients with knee injury who underwent MR imaging was calculated as follows: The cost of MR examination in all these patients plus the cost of all immediate therapeutic arthroscopies plus the cost of all procedures in patients with outcomes classified as failures was subtracted from the theoretical cost of immediate diagnostic arthroscopy in all patients.

RESULTS

After MR imaging, 44 of 103 patients (42.7%) underwent immediate surgery (Fig 1). The findings in these patients are displayed in Table 1. Among the 34 patients in Table 1 in whom the MR imaging protocol was followed and who underwent immediate therapeutic arthroscopy, 32 diagnoses based on findings on MR im-
ages were confirmed at surgery (accuracy, 94%). The two other patients had grade 3 changes in signal intensity without confirmation at arthroscopy.

The 59 other patients (57.3%) received continued nonsurgical treatment and did not undergo immediate arthroscopy. The diagnoses based on MR imaging findings in these patients are listed in Table 2. Fifty-five of these 59 patients (93%) were available for follow-up at a mean of 22 months (range of follow-up, 17–28 months). The outcome was successful in 49 of these 55 patients (89%) (Fig 1); 40 patients had normal function and no marked limitation in activity, six patients had undergone reconstruction of the ACL, and three had undergone arthroscopy with negative findings. The outcome in six of the 55 patients (11%) was considered a failure; four of these six patients had continued limitation in activity and two had undergone successful arthroscopic treatment of a plica.

Of the 44 patients in whom long-term follow-up was performed and who had not undergone arthroscopic surgery, only five reported a limitation in activity. In three of these patients, the outcome was considered a failure secondary to persistent symptoms and marked limitation in activity. Two of the five patients had only slight restriction in activity and no instability and indicated that they felt normal. Thirty of the 44 patients had occasional mild to moderate pain in the knee. Only one patient, however, complained of severe knee pain, and thus the outcome was considered a failure in this patient. Fifteen of the 44 patients had periodic swelling in the knee. Of the four patients with long-term follow-up whose outcomes were classified a failure, one had persistent swelling and one complained of knee instability. All four patients indicated that they did not feel normal. Four other patients indicated that they did not feel normal, but they had no limitation in activity, no swelling, and no instability; therefore, the outcome in these patients was not considered a failure.

Sixty-six patients presented with acute symptoms of less than 6 months duration and 37 patients with chronic symptoms. Thirty-one patients with acute symptoms underwent immediate surgery and 35 did not. Thirty-four of these 35 patients (97%) were available for follow-up at a mean of 21 months (range of follow-up, 18–28 months). In 31 of these 34 patients (91%) the outcome was classified a success (Fig 2); 24 patients had normal function and no marked limitation in activity, five had undergone ACL reconstruction, and two had undergone arthroscopy with negative findings. The outcome was a failure in three of the 34 patients (9%); these three patients had continuous limitation in activity. One patient was lost to long-term follow-up.

In the group with chronic symptoms, 13 patients underwent immediate surgery and 24 patients did not. Follow-up was performed in 21 of these 24 patients (88%) at a mean of 22 months (range of follow-up, 18–28 months). Of these 21 patients, 18 had successful outcomes (88%); 16 patients had normal function and no marked limitation in activity, one patient had undergone ACL reconstruction, and one patient had undergone arthroscopy with negative findings (Fig 3). In three patients (14%) the outcome was a failure because they had continued limitation in activity. Three patients were lost to long-term follow-up.

Cost-effectiveness (Fig 4) was calculated in the following manner: Before the use of MR imaging at our institution, all 103 patients would have undergone diagnostic arthroscopy at a total cost of $401,700. In this study, however, all 103 patients underwent MR imaging of the knee at a cost of $103,000. In addition, 44 patients underwent immediate therapeutic arthroscopy at a cost of $171,600, and
the outcome was classified a failure in six patients at a cost of $23,400. Therefore, the clinical strategy of performing MR imaging of the knee in all patients and then performing surgery only in patients with indications for surgery resulted in a net savings of $103,700.

Discussion

Before the use of MR imaging, all patients in this study would have undergone diagnostic arthroscopy. In this study, MR imaging affected patient treatment by enabling selection of patients with a surgical lesion and obviating an invasive procedure in the other patients. In addition to guiding treatment, MR imaging helps the surgeon plan therapeutic arthroscopy before surgery. Plans for meniscal repair can be made in appropriate patients on the basis of the MR examination. For example, isolated ACL injuries can be treated electively on the basis of instability patterns, whereas young active patients with combined meniscal tears and ACL disruption can be treated with meniscal repair and ACL reconstruction.

Diagnostic arthroscopy is considerably more expensive than MR imaging, and their accuracy is likely very similar. Many studies have evaluated the diagnostic accuracy of MR imaging of the knee (9-15,20,21). The wide range of reported accuracy rates may be due to a number of factors, such as equipment, imaging technique, and the expertise of the radiologist and arthroscopist. For example, accuracy in diagnosis of medial meniscus tears increased from 86% to 93%, sensitivity increased from 84% to 97%, and negative predictive value increased from 86% to 96% when a mobile 1.5-T imager was compared with a stationary 1.5-T imager (22). Using a 1.5-T magnet, Mink et al (13) reported an overall accuracy of 93%, which is very close to our overall accuracy of 94%. They also noted that the false-positive rate ranged from 6% to 16% among the 37 general orthopedic surgeons but was only 6% for the arthroscopist subspecialist. Quinn and Brown (23) have shown that some false-positive findings on MR images can be attributed to inadequate visualization of the meniscus at surgery and that diagnosis of a tear can be subjective. Clearly, the accuracy of arthroscopy is highly dependent on this surgeon’s expertise.

All prior studies have used arthroscopy as the standard against which MR imaging is compared. The problem with these studies is the failure to use the final outcome of the patients as the standard of comparison. For example, patients with a normal MR image could have a plica or degenerative fraying of the meniscus that is discovered at arthroscopy; this finding would suggest that MR imaging did not enable diagnosis. However, if the patient had not undergone arthroscopy on the basis of findings on MR images and the symptoms had disappeared, then the patient would have avoided diagnostic arthroscopy. The final outcome is a more relevant standard of comparison.

The MR imaging criteria used in this study guided management but were not strictly followed by the treating surgeons for various reasons. According to our protocol, seven patients with complete meniscal tears should have undergone therapeutic arthroscopy (Table 2). Of these patients, four refused surgery despite the recommendations of the treating surgeon and were doing well at long-term follow-up. In the fifth patient, a test for Lyme disease was positive, therapeutic arthroscopy was canceled, and the outcome was good. The sixth patient was doing well 11 months after MR imaging but was not available for long-term follow-up. The seventh patient, who had a combined chronic ACL tear and acute grade 3 meniscal tear, underwent delayed ACL reconstruction and partial meniscectomy. Exclusion of these patients from the group who underwent nonsurgical treatment should have increased the frequency of success if the protocol had been followed uniformly.

In 10 patients in our study, findings on MR images did not justify therapeutic arthroscopy on the basis of our protocol, but they underwent surgery anyway (Table 1). Although most patients with acute isolated ACL tears initially undergo nonsurgical treatment at our institution, three patients with such tears underwent immediate arthroscopic reconstruction of the ACL. In the seven other patients, arthroscopy was performed at the insistence of six patients and on the advice of the surgeon in one patient. In these seven patients, MR images were normal in two patients and revealed grade 2 changes in two patients. All four patients underwent arthroscopy, which was negative. In the fifth patient, chondromalia patellae was diagnosed on MR images but not documented at arthroscopy. The sixth patient had a grade 2 (possibly a grade 3) change on MR images and, on the surgeon's advice, underwent arthroscopy, which was negative. The seventh patient had a tibial plateau fracture, confirmed by means of arthroscopy. In view of the fact that arthroscopy was performed appropriately in 10 patients and was, appropriately, not performed in seven patients, strict compliance with the protocol would have obviated immediate arthroscopy in three patients.

Of the 11 patients who underwent delayed arthroscopy (Fig 1), six underwent ACL reconstruction, three underwent negative arthroscopy, and two underwent excision of plica. In only the two patients who underwent plica excision, the initial MR imaging failed to guide management toward appropriate treatment.

In a recent study, Boden et al (7) concluded that diagnostic arthroscopy would be more cost-effective than MR imaging if 78% of the patients underwent arthroscopy. In their study, MR imaging was not cost-effective because 87% of the patients underwent arthroscopy. However, their study had two major limitations. First, the final outcome of the patients was not ascertained. Second, no criteria for avoiding a diagnostic arthroscopy were stated. The surgeons may have used MR imaging to confirm diagnoses or just try out a new technology. In our study, only 43% of patients underwent immediate therapeutic arthroscopy on the basis of findings on MR images. Our findings that many patients with knee injuries

Cost Analysis Formula

\[(103 \times 3900) - [(103 \times 1000) + (44 \times 3900) + (6 \times 3900)] = 103,700\]

**Figure 4.** Cost analysis formula used in this study.

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show improvement after nonsurgical treatment is consistent with the study by Hede et al (24), who found that 14 of 36 patients (39%) decided not to undergo arthroscopy of the knee while on the surgical waiting list. Boeree et al (14) have suggested that the accuracy of MRI imaging should enable more appropriate selection of patients for whom arthroscopy would be beneficial. The authors postulate that such accuracy would eliminate the need for arthroscopy in one-third to one-half of those considered, on the basis of clinical findings, to have meniscal or cruciate derangement. Their hypothesis correlates well with the results of our study.

Finally, when one interprets the results of this study, several limitations should be considered. Reproduction of our results might not occur in centers with different equipment, imaging techniques, radiologists, or patient populations. The patients in our study attended a sports medicine tertiary referral clinic with sports medicine subspecialists and may represent a special population. However, a less specialized group of patients would likely include even more patients who do not have intraarticular lesions. Costs described in the study are specific to this university and cannot necessarily be extrapolated to other sites. Finally, costs associated with lost work time, physical therapy, and arthroscopic complications were excluded from our cost analysis equations. A more comprehensive study should include these factors.

References