MAGNETIC RESONANCE IMAGING OF THE KNEE IN CHILDREN AND ADOLESCENTS

ITS ROLE IN CLINICAL DECISION-MAKING

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Background: Recent studies have questioned the utility of magnetic resonance imaging in the diagnosis of pediatric knee disorders because of the morphologic changes during growth and the low accuracy of the formal interpretation of the magnetic resonance imaging scan by a radiologist. The purpose of this study was twofold: (1) to report the accuracy of formal interpretations of magnetic resonance imaging scans of the knee in children and adolescent patients by a radiologist, and (2) to determine the benefit, if any, of a personal review of the magnetic resonance imaging scan of the knee by the orthopaedic surgeon, as a routine part of the diagnostic evaluation.

Methods: A three-year prospective study of all patients who underwent knee arthroscopy performed by a single surgeon, at two children's hospitals, was completed. The analysis focused on the six most common diagnoses: anterior cruciate ligament tear, lateral meniscal tear, medial meniscal tear, osteochondritis dissecans, discoid lateral meniscus, and osteochondral fracture. The preoperative diagnosis of the surgeon was determined by integrating the history and the findings on the clinical examination, plain radiographs, and magnetic resonance imaging scans (including the radiologist's interpretation).

Results: Ninety-six patients with ninety-six abnormal knees were included. The mean age was 14.6 years at the time of surgery. Relative to operative findings, kappa values for the formal interpretations of the magnetic resonance imaging scans by a radiologist were 0.78 for an anterior cruciate ligament tear, 0.76 for a medial meniscal tear, 0.71 for a lateral meniscal tear, 0.70 for osteochondritis dissecans, 0.46 for discoid lateral meniscus, and 0.65 for osteochondral fracture. Relative to operative findings, kappa values for the preoperative diagnoses by the surgeon were 1.00 for an anterior cruciate ligament tear, 0.90 for a medial meniscal tear, 0.92 for a lateral meniscal tear, 0.93 for osteochondritis dissecans, 1.00 for discoid lateral meniscus, and 0.90 for osteochondral fracture. The preoperative diagnosis by the surgeon was better ($p < 0.05$) than the formal interpretation of the magnetic resonance imaging scans by the radiologist with respect to an anterior cruciate ligament tear, lateral meniscal tear, osteochondritis dissecans, and discoid lateral meniscus.

Conclusions: Integration of patient information with an orthopaedic surgeon's review of the magnetic resonance imaging scan of the knee in children and adolescent patients improves the identification of pathological disorders in four of the six categories evaluated. This study questions the necessity for and appropriateness of a routine interpretation of a magnetic resonance imaging scan of the knee in children and adolescents by a radiologist.

Level of Evidence: Diagnostic Level I. See Instructions to Authors for a complete description of levels of evidence.

Diagnosing knee disorders in children and adolescent patients can be difficult[1-10]. Harvell et al. reported that a correct clinical diagnosis was made preoperatively in only 70% (141) of 202 knees in adolescent patients[5]. The accuracy of the diagnostic process can be improved with an evaluation done by an examiner skilled in the treatment of pediatric knee disorders and with the use of magnetic resonance imaging studies and diagnostic arthroscopy[1,11,12]. Magnetic resonance imaging has become the study of choice for pathological disorders of the knee because it is a painless,

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noninvasive, three-dimensional, soft-tissue imaging study that is readily accessible and well accepted by patients and parents or caregivers. In the adult population, magnetic resonance imaging has been reported to be extremely accurate in identifying intra-articular pathologic conditions of the knee[13-19]. However, reports by Kocher et al. and Stanitski questioned the utility of magnetic resonance imaging of the knee in pediatric patients, mainly because of the low accuracy of the formal interpretation of the magnetic resonance imaging scans by the radiologist[11,12]. Clark and Ogden postulated that the discrepancy between the accuracy of magnetic resonance imaging of the knee in adults and pediatric patients is likely due to the morphological changes that occur during growth, which can alter the appearance of intra-articular structures on magnetic resonance imaging scans[20]. Postnatally, the meniscus undergoes gradual change, specifically decreasing vascularity and progressive adaptation of the collagen-fiber arrangement to biomechanical stress[13]. Takeda et al., in a report on magnetic resonance imaging of asymptomatic knees in pediatric patients who were less than sixteen years old, documented that seventy (65%) of 108 knees had an increased signal within a normal meniscus[21]. In the classification scheme proposed by Lotysch et al.[22], menisci with a normal appearance are classified as grade 0, whereas grades 1, 2, and 3 are typified by an increasingly abnormal intrameniscal signal, with grade-3 lesions being highly indicative of true meniscal tears. Takeda et al. demonstrated that meniscal signal changes classified as grades 2 or 3, which are suggestive of meniscal tears, were present in eight of ten children who were ten years old and in eight of twenty-four who were fourteen to fifteen years old[21].

Magnetic resonance imaging scans of the knee are commonly acquired to assist in identifying and quantifying intra-articular disorders. Because of the perceived level of expertise, the formal interpretation by the radiologist is often considered to be an accurate description of the knee disorder. Ideally, the information gathered from the formal interpretation by the radiologist assists the diagnostic and therapeutic process. However, if it is inaccurate, it may misdirect the patient's care. In the clinical setting, the orthopaedic surgeon is faced with several questions when presented with a magnetic resonance imaging scan of the knee: Is the interpretation of the magnetic resonance imaging scan an accurate representation of the pathological disorder? If faced with inconsistencies between the clinical examination and the formal interpretation of the magnetic resonance imaging scan, should the orthopaedic surgeon defer to the interpretation by the radiologist? Is there additional information to be obtained by personal review of the magnetic resonance imaging scan by the orthopaedic surgeon? The purpose of this study was twofold: (1) to report the accuracy of formal interpretations of magnetic resonance imaging scans of the knee in pediatric and adolescent patients by a radiologist, and (2) to determine whether there is a benefit in a personal review of the magnetic resonance imaging scan of the knee by the treating orthopaedic surgeon, as a routine part of the diagnostic evaluation.

Materials and Methods

A prospective study of all consecutive patients undergoing knee arthroscopy who had a preoperative magnetic resonance imaging scan of the involved knee was completed during a three-year period from March 1, 2000, to February 28, 2003. The study was performed at two tertiary-care children's hospitals with institutional review board approval. For study purposes, this analysis focused on the six most common diagnoses: anterior cruciate ligament tear, medial meniscal tear, lateral meniscal tear, discoid lateral meniscus, osteochondritis dissecans, and osteochondral fracture. Patients were included if the preoperative and/or operative diagnoses included one of these six disorders. Patients were excluded if they had previous surgery on the same knee or if they had a Wrisberg variant discoid lateral meniscus. Wrisberg variants were excluded because this diagnosis was typically made on clinical examination and, if there was no incarceration of the meniscus within the intercondylar notch, the knee had a classically normal appearance on magnetic resonance imaging[23,24]. One hundred and five patients with a preoperative magnetic resonance imaging scan underwent knee arthroscopy. Nine patients were excluded because of previous surgery on the same knee (four patients), patellar subluxation (three patients), and a medial plica and a dorsal defect of the patella (one patient each).

All patients were evaluated preoperatively in the outpatient clinic by the lead author (S.J.L.), who had six years of experience in pediatric orthopaedic sports medicine. A detailed physical examination of the knee and plain radiographs made with the patient standing (anteroposterior, lateral, notch, and Merchant views)[25] were completed on all patients. Forty-one patients presented at the initial evaluation with a magnetic resonance imaging scan without gadolinium, which was reviewed with parents or caregivers and patients at the time of an outpatient visit. After our evaluation, a magnetic resonance imaging scan was acquired for the children or adolescents without a prior magnetic resonance image who had a suspected meniscal disorder, ligament disruption (anterior and posterior cruciate ligament), osteochondral fracture, or loose bodies. For all magnetic resonance imaging scans ordered from our sports clinic, the pediatric fellowship-trained radiologists had access to the plain radiographs and the orthopaedic surgeon's presumptive diagnosis. Magnetic resonance imaging performed at our facility utilized a 1.5-T scanner (Siemens Medical Systems, Iselin, New Jersey). Standard imaging sequences for evaluation of the knee at our facility included coronal T1-weighted and fat-suppressed turbo spin-echo T2-weighted sequences, sagittal conventional spin-echo proton-density or T2-weighted dual-echo sequences, and axial fat-suppressed turbo spin-echo T2-weighted sequences. The radiologist's knowledge of the patient history and the findings on physical examination for those patients with a magnetic resonance imaging scan acquired prior to the initial clinic visit was unknown. Magnetic resonance imaging scans acquired prior to the initial outpatient evaluation from an outside imaging center were not reviewed by our in-house radiologists. The operating surgeon was not blinded to the

formal magnetic resonance imaging report and personally reviewed all magnetic resonance imaging scans and formal interpretations by the radiologist for all patients. The preoperative diagnosis was made by the surgeon after reviewing the history, the findings on the clinical examination and plain radiographs, and the radiologist's interpretation of the magnetic resonance imaging scans and by performing a personal review of the magnetic resonance imaging scans. Preoperatively, the surgeon's diagnoses were documented for each patient, specifically for study purposes, on a standardized data collection form. All arthroscopic procedures were performed by the lead author (S.J.L.) with the patient under general anesthesia. At the completion of each surgical case, all operative findings and procedures were documented on the data collection form.

Imaging

Minor findings on the magnetic resonance imaging reports, specifically effusions, bone contusions or edema, collateral ligament injuries, cartilage thinning in the absence of a defect, and meniscal cysts, were not included in the analysis. Meniscal lesions on the magnetic resonance imaging scans were classified according to the system of Lotysch et al.[22]. Grade-1 changes represent one or several punctate signal intensities not contiguous with an articular margin. Grade 2 indicates a linear intrameniscal signal intensity, and grade 3 represents the extension of the signal intensity to at least one articular surface. Only signal changes defined as grade 3 by Lotysch et al. were considered true meniscal tears, while grade-2 signal changes were not considered positive findings. Magnetic resonance imaging findings that were recorded as "possibly" or "probably" positive on the formal interpretation by the radiologist were considered to be positive findings for study purposes. In addition, "partial" injuries to the anterior cruciate ligament were defined as positive findings on the magnetic resonance imaging scans.

Statistical Methods

We compared the findings on the magnetic resonance imaging report (the radiologist's interpretation) and the orthopaedic surgeon's preoperative diagnosis with the findings at the time of arthroscopic surgery, using sensitivity, specificity, positive and negative predictive values, and kappa statistics. Sensitivity was defined as the percentage of positive findings on magnetic resonance imaging scans made (preoperatively) for patients with a positive diagnosis upon arthroscopic surgery. Of the patients without a specific diagnosis according to the findings on preoperative magnetic resonance imaging, the percentage who had negative findings upon arthroscopic surgery was defined as specificity. Confidence intervals (95%) for sensitivity and specificity were calculated on the basis of formulae for proportions[26].

Kappa statistics were calculated separately for magnetic resonance imaging findings and the preoperative diagnosis relative to the intraoperative findings. A kappa value of >0.80 indicates nearly perfect agreement[27]. Kappa measures the extent of the agreement between the magnetic resonance imaging findings (the preoperative diagnosis) and the intraoperative findings, taking into account chance agreement. The kappa values were statistically compared with use of the normal distribution. All analyses were conducted separately for all diagnoses. Because forty-one (43%) of ninety-six patients were referred to one of our tertiary-care children's hospitals with a magnetic resonance imaging scan, we assessed the differences in sensitivity, specificity, and kappa values between magnetic resonance imaging scans performed elsewhere and those acquired at our hospital for all meniscal injuries. A p value of <0.05 was considered to be significant.

Results

During the three-year study period, the lead author (S.J.L.) evaluated 1007 new patients with knee symptoms. Of those new patients, ninety-six (ninety-six knees) satisfied the inclusion criteria for the study. There were fifty-nine male and thirty-seven female patients, with a mean age of 14.6 years (range, 7.3 to 18.7 years). The right knee was involved in sixty patients and the left, in thirty-six patients. Seventy patients reported an injury to the knee, which was associated with the onset of knee symptoms. The median duration of the symptoms was thirteen weeks (range, two weeks to five years). The presence of symptoms prior to the primary evaluation was two months or less (fifty patients), three to six months (twelve patients), seven to nine months (nine patients), ten to twelve months (eight patients), and thirteen months or greater (seventeen patients). Magnetic resonance imaging scans were performed at our medical center for fifty-five patients, while forty-one patients had scans performed at outside facilities. There were 131 final postoperative diagnoses (Table I). At the time of knee arthroscopy, 121 procedures were performed (Table II).

No difference was identified when the formal interpretations of the magnetic resonance imaging scans by the radiologists at our children's hospital and the interpretations made at outside centers were compared ($p = 0.181$ to 0.844). Thus, data from all magnetic resonance imaging centers were

TABLE I Final Diagnoses in Ninety-six Knees

Diagnosis	No. of Knees
Anterior cruciate ligament tear	39
Lateral meniscal tear	27
Osteochondritis dissecans	19
Medial meniscal tear	18
Discoid lateral meniscus	10
Patella dislocation	7
Osteochondral fracture	5
Loose body	4
Posterior cruciate ligament tear	2
Total	131

TABLE II Procedures Performed in Ninety-two Patients*

Procedure	No. of Patients
Anterior cruciate ligament reconstruction	36
Lateral meniscectomy (partial)	17
Medial meniscectomy (partial)	13
Patellar chondroplasty-drilling arthroplasty	12
Discoid meniscus saucerization	10
Lateral meniscal repair	8
Patellar realignment	6
Osteochondritis dissecans drilling and/or pinning	6
Medical meniscal repair	5
Loose body removal	4
Osteochondral transfer	3
Posterior cruciate ligament reconstruction	1
Total	121

*Four patients who had diagnostic arthroscopy without abnormal findings are excluded.

pooled for each diagnosis. Sensitivities, specificities, and the positive and negative predictive values for the six diagnoses are reported in the Appendix. Kappa values calculated for the formal interpretation of magnetic resonance imaging scans by the radiologists were 0.78 for an anterior cruciate ligament tear, 0.76 for a medial meniscal tear, 0.71 for a lateral meniscal tear, 0.70 for osteochondritis dissecans, 0.46 for discoid lateral meniscus, and 0.65 for osteochondral fracture. Kappa values calculated for the surgeon's preoperative diagnoses, including interpretation of the magnetic resonance imaging scans, were 1.00 for an anterior cruciate ligament tear, 0.90 for a medial meniscal tear, 0.92 for a lateral meniscal tear, 0.93 for osteochondritis dissecans, 1.00 for discoid lateral meniscus, and 0.90 for osteochondral fracture (see Appendix). The preoperative diagnoses by the surgeon were significantly ($p < 0.05$) better than the formal interpretation of the magnetic resonance imaging scans by the radiologist for an anterior cruciate ligament tear, a lateral meniscal tear, osteochondritis dissecans, and discoid lateral meniscus. Despite differences in the kappa values for a medial meniscal tear and osteochondral fracture, no significant difference was detected.

Discussion

The difficulty in diagnosing pediatric and adolescent knee problems has been well documented[1-10]. Prior to the widespread access to and use of magnetic resonance imaging, knee arthroscopy had been advocated as a valuable diagnostic tool[9,28-30]. Several studies involving a series of pediatric patients have shown that a substantial percentage of knees examined arthroscopically were not found to have surgically treatable lesions[9,30,31]. Eiskjaer and Larsen reported on a series of patients from one to eighteen years of age who underwent arthroscopy because of acute hemarthroses of the knee[4]. In that study, forty-two (23%) of 182 knees were classified as normal at the time of arthroscopy (no identifiable intra-articular disorder), whereas sixty-nine knees (38%) had "no surgically treatable abnormality."[4] Suman et al. reported no surgically treatable abnormality at arthroscopy in eleven of nineteen patients who were less than thirteen years old and in fifteen of forty-eight patients who were fourteen to seventeen years old[9]. These series were collected in the 1980s during the initial enthusiasm for knee arthroscopy and prior to the widespread use of magnetic resonance imaging. In our study population, only four of ninety-six patients underwent an arthroscopic examination in which we could not identify an intra-articular abnormality. The role of arthroscopy as a diagnostic and therapeutic tool is unquestioned; however, in light of this study, its role as a purely diagnostic tool may need to be reexamined. It is easy to minimize knee arthroscopy in terms of its level of intervention because of the use of small incisions and the patient's relatively rapid recovery; however, in our experience as well as others, most pediatric and adolescent patients and their parents or caregivers consider arthroscopic surgery to have a similar level of risk and invasiveness as any open procedure[9,30]. In pediatric and adolescent patients, arthroscopy requires the use of general anesthesia and has the same risks inherent to other orthopaedic surgical procedures and should be used as a diagnostic tool only as a last resort. Casscells nicely summarized this issue, "Like any other test that requires mechanical means or laboratory facilities, diagnostic arthroscopy should not be used as a substitute for careful clinical examination. Looking is no substitute for thinking."[2]

Over the last twenty years, magnetic resonance imaging has rapidly evolved and expanded as a result of technological improvements and experience. Magnetic resonance imaging, when combined with the findings on plain radiographs, the history, and the clinical examination, currently provides the most accurate information with regard to abnormality of the anterior cruciate ligament and menisci in the adult patient[32,33]. Despite the overall utility of magnetic resonance imaging for the diagnosis of musculoskeletal abnormalities, its routine use is not recommended, even in adults[31,34]. In order to avoid overdiagnosis of knee disorders, correlation with the findings on clinical examination and plain radiographs is essential[32,34]. We support the general consensus in published reports that magnetic resonance imaging should be done selectively, on the basis of patient history, clinical examination, and plain radiographic findings[11,12,31,32,34].

The use of magnetic resonance imaging for disorders of the knee in pediatric and adolescent patients has been previously reported by Kocher et al. and Stanitski[11,12]. In both of those analyses, the formal magnetic resonance imaging report (the radiologist's interpretation) and the clinical diagnosis (without input from the magnetic resonance imaging scans) were compared with the findings at the time of arthroscopic surgery. In the report on twenty-eight knees in twenty-eight patients by Stanitski, twenty (71%) of the diagnoses based on the magnetic resonance imaging reports were incorrect com-

pared with only six incorrect diagnoses based on the clinical findings. The data analysis demonstrated that magnetic resonance imaging would not have improved the accuracy of any of the clinical diagnoses (anterior cruciate ligament tear, meniscal tears, or osteochondritis dissecans lesions). Kocher et al., in a retrospective analysis of 118 knees in 113 patients, documented no significant difference between the clinical examination and the findings on magnetic resonance imaging with respect to agreement with the arthroscopic findings, sensitivity, and overall specificity. Only medial meniscal tears were better diagnosed by magnetic resonance imaging. Those two studies, from centers with extensive experience with pediatric knee problems, raised questions about the utility of magnetic resonance imaging in the pediatric population and, more specifically, the utility of the formal interpretation by radiologists. As those studies demonstrated, the formal interpretation of the magnetic resonance imaging scans by the radiologist can be less than optimal, perhaps because of a lack of clinical information, absence of a clinical examination, and/or the lack of surgical knowledge of knee anatomy and pathological conditions. Thus, the radiologist's interpretation of a magnetic resonance imaging scan of the knee can be inaccurate and perhaps not reliable.

In our experience, the formal interpretation of the magnetic resonance imaging scan by the radiologist commonly has inaccuracies and may not correlate with the initial clinical diagnoses. However, during a review of magnetic resonance imaging scans prior to the initiation of this study, it became evident to the lead author (S.J.L.) that the magnetic resonance imaging studies themselves were not inaccurate, but, rather, the interpretation by the radiologist was inaccurate. Hence, the thrust of this study was to answer the question: Can we improve the utility of magnetic resonance imaging scans with a personal review by the surgeon? The answer is yes. By combining the history and the findings on physical examination, plain radiographs, and magnetic resonance imaging scans, we were able to achieve the highest overall diagnostic accuracy yet reported. A comparison of our results with those in the previous series reported by Kocher et al.[11] and Stanitski[12] is presented in the Appendix. In addition, only four (4%) of ninety-six patients had unnecessary diagnostic arthroscopic procedures, and, after a follow-up ranging from one to four years, no patient in this study had been found to have an intra-articular abnormality that was missed at the time of arthroscopy. Hence, in centers with less experience with the treatment of knee problems in pediatric and adolescent patients, magnetic resonance imaging scans can be very helpful, enabling the treating orthopaedic surgeon to be highly accurate diagnostically, especially when the surgeon personally reviews the scan. The more accurate the preoperative diagnosis, the better prepared the surgeon will be to deal with the disorder by having the necessary equipment, surgical assistants, and time. In addition, with highly accurate preoperative diagnoses, the discussions with families can be more constructive, thereby permitting adequate preoperative preparation.

In the day-to-day operations of a clinical practice, it is relatively easy to obtain the formal interpretation of knee magnetic resonance imaging by the radiologist but acquiring the actual magnetic resonance imaging scan can be a challenging task. However, for optimal patient care, we advocate that the orthopaedic surgeon personally review all magnetic resonance imaging scans of the knee for pediatric and adolescent patients. Reliance on the radiologist's formal interpretation can lead to diagnostic inaccuracies and to a delay in the appropriate treatment. In addition, this study raises the question of the need for a radiologist's interpretation of magnetic resonance imaging scans of the knee in children and adolescents.

Appendix

eA Tables showing comparative statistics between the radiologist's report and the surgeon's preoperative diagnosis for all six disease categories and also a comparison of the results of this study with two others are available with the electronic versions of this article, on our web site at jbjs.org (go to the article citation and click on "Supplementary Material") and on our quarterly CD-ROM (call our subscription department, at 781-449-9780, to order the CD-ROM). ■

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