Use of the "Two-Slice-Touch" Rule for the MRI Diagnosis of Meniscal Tears

Arthur A. De Smet[1]
Michael J. Tuite

OBJECTIVE. We reviewed our experience with knee MRI to determine if using the "two-slice-touch" rule increased our positive predictive value for diagnosing meniscal tears. This rule classifies a meniscus as torn if there are two or more MR images with abnormal findings and as possibly torn if there is only one MR image with an abnormal finding. We also compared our sensitivity and specificity using fast spin-echo imaging with previously reported studies.

MATERIALS AND METHODS. We reviewed the medical records of 174 patients who had knee MR examinations and correlative knee arthroscopy to determine our accuracy when we diagnosed menisci as torn, possibly torn, or intact using knee arthroscopy as the gold standard.

RESULTS. Our positive predictive value increased from 91% to 94% ($p = 0.37$) for medial meniscal tears and from 83% to 96% ($p = 0.02$) for lateral meniscal tears when using the two-slice-touch rule compared with the standard criterion of diagnosing a meniscus as torn if one or more images are abnormal. When using the standard criterion, we had 95% sensitivity and 85% specificity for diagnosing medial meniscal tears and 77% sensitivity and 89% specificity for diagnosing lateral meniscal tears.

CONCLUSION. When using the two-slice-touch rule, we had an increased positive predictive value for diagnosing menisci as torn, which was statistically significant for the lateral meniscus. Our accuracy using the standard criterion with fast spin-echo imaging was comparable to that reported in previous studies with spin-echo imaging.

In the past 20 years, many authors have studied the accuracy of MRI for diagnosing meniscal tears [1]. However, only one previous study has reported that false-positive diagnoses of a meniscal tear could be reduced by noting the number of abnormal findings on meniscal images on the MR examination [2]. In that study, a meniscus was found to be highly likely torn if two or more MR images of a meniscus had distortion or signal to the meniscal surface, and considerably less likely to be torn if only one MR image of a meniscus showed an abnormal finding [2]. These findings have been presented as the "two-slice-touch" rule at national meetings (De Smet AA, presented at the 2005 annual meeting of the Radiological Society of North America). However, this concept of diagnosing a meniscal tear as torn or possibly torn based on the number of abnormal MR images has not been used in any other study on the MR diagnosis of meniscal tears and has not been validated when used prospectively.

We have used the two-slice-touch rule for diagnosing meniscus tears on knee MRI for the past 10 years. Four years ago, we changed our MRI sequences from conventional spin echo to fast spin echo when we assessed patients for meniscal tears. Although several authors have reported comparable accuracy for diagnosing meniscal tears when using conventional and fast spin-echo imaging, a recent study found a significantly lower accuracy when using fast spin-echo imaging [3–5].

Because of this controversy regarding fast spin-echo imaging and the lack of a prospective study confirming the usefulness of the two-slice-touch rule, we reviewed our experience in diagnosing meniscal tears on MRI. We now report our results when using the two-slice-touch rule to diagnose a meniscus as torn, possibly torn, or not torn. We also compare our results using fast spin-echo imaging with those reported using both conventional and fast spin-echo imaging.

Materials and Methods

The study was performed in compliance with Health Insurance Portability and Accountability Act (HIPAA) regulations and with approval from

Keywords: biomedical statistics, knee, meniscal tears, MRI, musculoskeletal imaging

DOI:10.2214/AJR.05.1354

Received August 4, 2005; accepted after revision August 31, 2005.

[1]Both authors: Department of Radiology, University of Wisconsin Medical School and Hospital, Radiology - E3/311, 600 Highland Ave., Madison, WI 53792. Address correspondence to A. A. De Smet.

AJR 2006; 187:911–914

0361–803X/06/1874–911

our institutional review board. A waiver of informed consent was obtained from our institutional review board before performing the study.

Patient Selection and Medical Records Review

We reviewed the medical records of 561 consecutive patients who had knee MRI examinations at our institution from July through October 2003. We noted in how many menisci we diagnosed a possible tear. We then determined the accuracy of our MR interpretations using the results of knee arthroscopy as the gold standard in all 174 patients who had correlative arthroscopic surgery at our institution after their knee MRI examination and who had not had prior meniscal surgery. The knee arthroscopies were performed by any one of three fellowship-trained orthopedic surgeons specializing in sports medicine and arthroscopy. Each arthroscopist had 7 or more years of experience as a faculty member at an academic medical center.

MRI

The MRI examinations were interpreted by any one of seven fellowship-trained musculoskeletal radiologists. The MRI experience of these observers ranged from 1 to 20 years. By prior agreement within the musculoskeletal division, each meniscus was evaluated prospectively using the following rules: A meniscus was diagnosed as torn if meniscal distortion or intrameniscal signal contacting the meniscal articular surface was noted on two or more images for a given meniscus. These two images need not be consecutive and could be two coronal images, two sagittal images, or one coronal image and one sagittal image. A meniscus was diagnosed as possibly torn if only one MR image was abnormal and as not torn if no image showed distortion or definite signal contacting the surface. Identification of a displaced meniscal fragment was also considered to be a definite sign of a tear, although in such patients there is almost invariably meniscal distortion or meniscal signal to the surface on more than one image.

The interpreters of these MRI studies used the two indirect signs of a meniscal tear—disruption of the popliteomeniscal fascicle and posteromedial tibial bone bruise—to look more carefully for an adjacent meniscal tear but diagnosed a definitely torn or possibly torn meniscus on the basis of the two-slice-touch rule [6, 7].

All knee MRI examinations were performed using our standard protocol on a 1.5-T MR magnet (Signa, GE Healthcare) using a knee phased-array cylindric coil. All studies consisted of coronal fast spin-echo T1-weighted, coronal fat-saturated fast spin-echo proton density–weighted, sagittal fast spin-echo proton density–weighted, and sagittal fat-saturated fast spin-echo T2-weighted images.

A field of view of 14 cm, slice thickness of 3 mm with a 1.5-mm interslice gap, and a matrix of 256 × 192 were used for all four sequences, except that a matrix of 256 × 224 was used for the coronal T1-weighted images. The parameters were as follows for the coronal T1-weighted images: TR range/TE, 600–700/17; 1 signal average; and echo-train length, 3; for the coronal fat-saturated proton density–weighted images: 1,800–2,000/17; 1 signal average; and echo-train length, 4; for the sagittal proton density–weighted images: 2,000–2,200/17; 1 signal average; and echo-train length, 4; and for the sagittal T2-weighted fat-saturated sequences: 3,000–3,400/60; 1 signal average; and echo-train length, 6. The scanning time for each of the four sequences was between 2 and 3.5 minutes.

Data Analysis

Sensitivity, specificity, positive predictive value, and negative predictive value were calculated for the medial and lateral menisci in two ways: first, by considering all MRI diagnoses of a tear or possible tear as positive for a tear; and second, by excluding the cases of possible tears. By calculating our accuracy using both methods, we could compare changes in accuracy when the two-slice-touch rule was used. Chi-square analysis was used to compare the data for these two sets of accuracy calculations. A difference with a p value of less than 0.05 was considered statistically significant.

Our results were then compared with those of prior studies reporting the accuracy of diagnoses of meniscal tears using conventional spin-echo and fast spin-echo imaging. We calculated our accuracy considering menisci diagnosed as torn or possibly torn as indicating a tear because those prior studies used the presence of one or more MR images showing meniscal distortion or intrameniscal signal contacting the meniscal surface as evidence of a meniscal tear. We selected for comparison only studies that reported at least 100 patients with arthroscopic correlation. For series of fewer than 100 patients, significant variation can occur by random chance in the calculated accuracy values [8].

Results

For the 174 patients who underwent correlative knee arthroscopy, the MRI diagnoses are compared with the arthroscopic findings in Table 1. The MRI diagnosis of a possible tear was made in seven (4.0%) of 174 medial menisci. Tears were found at arthroscopy in three (43%) of these seven medial menisci diagnosed as possible tears. The MRI diagnosis of a possible tear was made in 11 (6.3%) of the 174 lateral menisci. Tears were found at arthroscopy in two (18%) of these 11 lateral menisci diagnosed as possible tears.

The data in Table 1 were used to calculate accuracy as given in Table 2. Because more than half of the menisci diagnosed as possible tears were found to be intact at arthroscopy,

TABLE 1: Correlation of MRI Diagnoses of Meniscal Tears with Arthroscopic Findings in 174 Patients

MRI	Arthroscopy		
	Torn	Not Torn	Total
Medial meniscus			
Torn	98	6	104
Possibly torn	3	4	7
Not torn	5	58	63
Total	106	68	174
Lateral meniscus			
Torn	53	2	55
Possibly torn	2	9	11
Not torn	16	92	108
Total	71	103	174

the specificity and positive predictive value increased for both medial and lateral menisci when only menisci with two or more abnormal images were considered to be torn. However, the differences were statistically significantly different only in the lateral meniscus.

In Table 3, our results are compared with those of nine prior studies in which more than 100 patients were evaluated using 1.5-T MR magnets followed by arthroscopic correlation [9–18].

Discussion

This study was undertaken to confirm that using the two-slice-touch rule increased our positive predictive value for diagnosing a meniscal tear, and to determine whether our accuracy using fast spin-echo imaging was comparable to that previously reported.

With regard to our first objective, we found a significantly increased positive predictive value when we diagnosed a lateral meniscus as definitely torn on the basis of two or more abnormal images when compared with diagnosing a tear on the basis of one or more abnormal images (Table 2). Although the finding was not statistically significantly different, we also had fewer false-positive diagnoses of medial meniscal tears when we diagnosed a medial tear as torn only in the presence of two or more abnormal MR images (Table 2).

Our results confirm a prior study in which the authors retrospectively calculated a positive predictive value of 94% for medial menisci and 90% for lateral menisci when menisci were diagnosed as torn only when two or more images showed abnormal findings [2]. We had similar results, with a positive predictive value of 94% for tears

TABLE 2: Comparison of Diagnostic Accuracy When Considering Torn and Possibly Torn Diagnoses as Positive for a Tear Versus Considering Only Torn Diagnoses as Positive in 174 Menisci with Arthroscopic Correlation

Performance Measure	Criterion for Positive Diagnosis of Meniscal Tear		p[b]
	Torn and Possibly Torn	Torn Only[a]	
Medial meniscus			
Sensitivity (%)	95 (101/106)	95 (98/103)	0.96
Specificity (%)	85 (58/68)	91 (58/64)	0.35
Positive predictive value (%)	91 (101/111)	94 (98/104)	0.37
Negative predictive value (%)	92 (58/63)	92 (58/63)	1.0
Lateral meniscus			
Sensitivity (%)	77 (55/71)	77 (53/69)	0.93
Specificity (%)	89 (92/103)	98 (92/94)[c]	0.02
Positive predictive value (%)	83 (55/66)	96 (53/55)[c]	0.02
Negative predictive value (%)	85 (92/108)	85 (92/108)	1.0

[a]Excluding possibly torn by using the two-slice-touch rule.
[b]For differences.
[c]Statistically significant increase for lateral meniscus when two or more images show abnormal finding.

TABLE 3: Reported Accuracy of Conventional Spin-Echo and Fast Spin-Echo MRI at 1.5 T for Diagnosing Meniscal Tears Compared with Arthroscopy

Study	Year	No. of Patients	Medial Meniscus		Lateral Meniscus	
			Sensitivity (%)	Specificity (%)	Sensitivity (%)	Specificity (%)
Conventional spin echo						
Crues et al. [9]	1987	144	87	91	88	98
Mink et al. [10]	1988	242	97	89	92	91
Fischer et al. [12]	1991	483	96	84	70	95
Quinn and Brown [13]	1991	260	86	94	72	96
De Smet and Graf [14]	1994	400	93	87	80	93
Justice and Quinn [15]	1995	561	96	91	82	98
Kojima et al. [16]	1996	202	95	93	73	98
Rubin et al. [17]	1998	330	93	86	86	92
Fast spin echo						
Cheung et al. [18]	1997	289	89	94	72	93
Current study	2004	174	95	85	77	89

of the medial meniscus and 96% for tears of the lateral meniscus (Table 2). In the earlier study, 55% of medial menisci and 30% of lateral menisci with one abnormal MR image were found to be torn at arthroscopy [2]. We had similar results in that a tear was found at arthroscopy in only 43% of the medial and 18% of the lateral menisci that had one abnormal MR image.

We emphasize that the use of the two-slice-touch rule does not change the criteria for the MR diagnosis of a meniscal tear. The criteria for diagnosing meniscal tears with knee MRI have not changed since the original large patient series reported in the late 1980s [9, 10]. As described in a recent review, these criteria are intrameniscal signal contacting the articular surface of the meniscus, distortion of meniscal shape, and identification of a displaced meniscal fragment [1].

The advantage of the two-slice-touch rule is that it identifies a small subset of patients with signal to the surface on only a single image in whom a meniscal tear is less likely. We diagnosed 4% of the medial and 6.3% of the lateral menisci as possibly torn. If we had used the standard criterion of a single abnormal image for diagnosing a meniscus as torn and diagnosed these menisci as torn, our positive predictive value would have been lower. Only one retrospective study before ours has used the criterion that a definite tear is diagnosed only when two or more MR images are abnormal [11]. That study considered a tear to be present when there were two or more consecutive abnormal images, but it did not discuss how menisci with one definitely abnormal image were classified [11]. We cannot compare our findings in detail with those of that study because its focus was the diagnosis of displaced fragments, and there are limited data on the accuracy of diagnosing tears without displaced fragments [11].

The sports medicine physicians at our institution have expressed how much they value our high positive predictive value for the diagnosis of a meniscal tear when using the two-slice-touch rule. Also, by using the category of a possible tear, we give them more flexibility in managing these patients than if we diagnosed their menisci as definitely torn. Because these patients have an MRI abnormality on only one image, they often have only a small tear if a tear is present. Therefore, conservative treatment rather than surgical treatment can be used if clinically appropriate.

With regard to the second purpose of this study, we found that our sensitivity and specificity for diagnosing meniscal tears were comparable to those previously reported using both conventional and fast spin-echo imaging (Table 3). Our sensitivity of 95% for diagnosing medial meniscal tears is at the upper end of reported values for nine large series in which patients had MRI studies using high-field-strength 1.5-T magnets. Our sensitivity of 77% for diagnosing lateral meniscal tears was in the middle of the reported range of 70–92% (Table 3).

Although a previous article comparing conventional spin-echo and fast spin-echo imaging concluded that fast spin-echo imaging is inferior to conventional spin-echo imaging for the diagnosis of meniscal tears [19], later studies have found no significant difference in accuracy when comparing fast and conventional spin-echo imaging [3, 4]. More recently, a sensitivity of 80% was reported for the MRI diagnosis of meniscal tears when using fast spin-echo imaging compared with 93% when using conventional spin-echo imaging [5]. Those authors strongly advocated that fast spin-echo imaging not be used for diagnosing meniscal tears [5]. They based this recommendation on their study and a review of the literature in which fast spin-echo imaging had an average sensitivity of approximately 80% for meniscal tears whereas conventional spin-echo imaging had a sensitivity of more than 90% [5]. However, Vande Berg et al. [11] reported a sensitivity of 96% for diagnosing meniscal tears using fast spin-echo imaging.

Fast spin-echo imaging has the potential for decreased accuracy in the diagnosis of meniscal tears because of the increased blurring seen in fast spin-echo sequences, especially when a short TE is used [5, 19]. However, other studies have noted that the short TE blurring can be reduced by using a shorter echo-train length and higher performance gradients, which reduce blurring by permitting shorter interecho spacing, and by using the second echo as the effective TE [20]. During the time of the MR scans analyzed in this study, we used an echo-train length of 4 for our sagittal proton density–weighted images but did not have the higher-speed gradients on our MR unit to allow shorter interecho spacing. Despite the lack of high-speed gradients, our sensitivity of 95% for medial meniscal tears was near the upper end of the range of reported sensitivities in other studies. Our sensitivity of 77% for lateral meniscal tears, although lower than we would like, is comparable to other studies.

In our opinion, the optimal MRI parameters for diagnosing a meniscal tear have not been defined. Probably there are important interactions between each of the multiple imaging parameters used in MRI. Another variable that has not been fully studied is the value of adding fat saturation to the proton density–weighted sagittal sequence. Sagittal fat-saturated proton density–weighted images were used in the two recent studies that reported a sensitivity of 93% for diagnosing meniscal tears using conventional spin-echo imaging and 96% when using fast spin echo [5, 11].

We reviewed the studies listed in Table 3 to determine the range of variation in imaging parameters in these studies. The variations in pixel size used in these studies are significant, with the field of view varying from 14 to 18 cm and the matrix size varying from 256 × 192 to 512 × 346. In those same studies, slice thickness varied from 3 to 5 mm and interslice gaps varied from none to 1.5 mm. Similarly, the types of surface coils and the number of excitations also varied considerably, which would probably give differing signal-to-noise ratios in the MR images. We believe that with all the variables that can be adjusted, it is possible that many different combinations of imaging parameters will give comparable accuracy for the diagnosis of meniscal tears.

Limitations of our study include the lack of direct comparison of conventional and fast spin-echo imaging. It would have been preferable if we had imaged all 561 patients with both conventional and fast spin-echo imaging and performed independent interpretations of each imaging set. Such a comparison would not have been possible in our busy clinical practice because the time to perform each MRI examination would be more than doubled.

A second limitation is a possible selection bias. We selected the 174 patients for this study from a consecutive series of 561 knee MRI examinations in order to use arthroscopy as the gold standard. However, the decisions of the surgeons to operate on a given patient depend on many variables, including the patients' symptoms and physical findings and the surgeons' review of our interpretations of the MR examinations. This limitation is unavoidable because it would be inappropriate for every patient undergoing MRI of the knee to have subsequent knee arthroscopy.

In addition, the size and type of the tear may also influence the surgeon's decision to operate on a given patient. We would expect that patients with large or displaced tears would be more likely to have knee arthroscopic surgery than patients with small tears. Thus, studies using operative findings as the gold standard for MRI accuracy may have more of the larger or displaced tears that are easier to diagnose on MRI.

In summary, we have shown that by prospectively diagnosing menisci as torn when there are two or more MR images with meniscal signal to the surface or distortion, we had a high positive predictive value for a tear to be found at arthroscopy. In contrast, menisci with only one abnormal MR image were considerably less likely to be found to be torn at arthroscopy. We also found an accuracy for diagnosing meniscal tears using fast spin-echo imaging comparable to that reported in previous studies using either conventional or fast spin-echo imaging.

References

1. Rubin DA, Paletta GA Jr. Current concepts and controversies in meniscal imaging. *Magn Reson Imaging Clin N Am* 2000; 8:243–270
2. De Smet AA, Norris MA, Yandow DR, Quintana FA, Graf BK, Keene JS. MR diagnosis of meniscal tears of the knee: importance of high signal in the meniscus that extends to the surface. *AJR* 1993; 161:101–107
3. Escobedo EM, Hunter JC, Zink-Brody GC, Wilson AJ, Harrison SD, Fisher DJ. Usefulness of turbo spin-echo MR imaging in the evaluation of meniscal tears: comparison with a conventional spin-echo sequence. *AJR* 1996; 167:1223–1227
4. Anderson MW, Raghavan N, Seidenwurm DJ, Greenspan A, Drake C. Evaluation of meniscal tears: fast spin-echo versus conventional spin-echo magnetic resonance imaging. *Acad Radiol* 1995; 2:209–214
5. Blackmon GB, Major NM, Helms CA. Comparison of fast spin-echo versus conventional spin-echo MRI for evaluating meniscal tears. *AJR* 2005; 184:1740–1743
6. Blankenbaker DG, De Smet AA, Smith JD. Usefulness of two indirect MR imaging signs to diagnose lateral meniscal tears. *AJR* 2002; 178:579–582
7. Kaplan PB, Gehl RH, Dussault RG. Bone contusions of the posterior lip of the medial tibial plateau (contrecoup injury) and associated internal derangements of the knee at MR imaging. *Radiology* 1999; 211:747–753
8. De Smet AA, Norris MA, Yandow DR, Graf BK, Keene JS. Diagnosis of meniscal tears of the knee with MR imaging: effect of observer variation and sample size on sensitivity and specificity. *AJR* 1993; 160:555–559
9. Crues JV III, Mink J, Levy TL, Lotysch M, Stoller DW. Meniscal tears of the knee: accuracy of MR imaging. *Radiology* 1987; 164:445–448
10. Mink JH, Levy T, Crues JV III. Tears of the anterior cruciate ligament and menisci of the knee: MR imaging evaluation. *Radiology* 1988; 167:769–774
11. Vande Berg BC, Malghem J, Poilvache P, Maldague B, Lecouvet FE. Meniscal tears with fragments displaced in notch and recesses of knee: MR imaging with arthroscopic comparison. *Radiology* 2005; 234:842–850
12. Fischer SP, Fox JM, Del Pizzo W, Friedman MJ, Snyder SJ, Ferkel RD. Accuracy of diagnoses from magnetic resonance imaging of the knee: a multicenter analysis of one thousand and fourteen patients. *J Bone Joint Surg Am* 1991; 73:2–10
13. Quinn SF, Brown TF. Meniscal tears diagnosed with MR imaging versus arthroscopy: how reliable a standard is arthroscopy? *Radiology* 1991; 181:843–847
14. De Smet AA, Graf BK. Meniscal tears missed on MR imaging: relationship to meniscal tear patterns and anterior cruciate ligament tears. *AJR* 1994; 162:905–911
15. Justice WW, Quinn SF. Error patterns in the MR imaging evaluation of menisci of the knee. *Radiology* 1995; 196:617–621
16. Kojima KY, Demlow TA, Szumowski J, Quinn SF. Coronal fat suppression fast spin-echo images of the knee: evaluation of 202 patients with arthroscopic correlation. *Magn Reson Imaging* 1996; 14:1017–1022
17. Rubin DA, Kettering JM, Towers JD, Britton CA. MR imaging of knees having isolated and combined ligament injuries. *AJR* 1998; 170:1207–1213
18. Cheung LP, Li KCP, Hollett MD, Bergman AG, Herfkens RJ. Meniscal tears of the knee: accuracy of detection with fast spin-echo MR imaging and arthroscopic correlation in 293 patients. *Radiology* 1997; 203:508–512
19. Rubin DA, Kneeland JB, Listerud J, Unerberg-Davis SJ, Dalinka MK. MR diagnosis of meniscal tears of the knee: value of fast spin-echo vs conventional spin-echo pulse sequences. *AJR* 1994; 162:1131–1135
20. Kowalchuk RM, Kneeland JB, Dalinka MK, Siegelman ES, Dockery WD. MRI of the knee: value of short echo time fast spin-echo using high performance gradients versus conventional spin-echo imaging for the detection of meniscal tears. *Skeletal Radiol* 2000; 29:520–524