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Roman M. Kowalchuk
J. Bruce Kneeland
Murray K. Dalinka
Evan S. Siegelman
W. Dee Dockery

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

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R.M. Kowalchuk, M.D.
Ph.D., J.B. Kneeland, M.D. (✉),
M.K. Dalinka, M.D.
E.S. Siegelman, M.D.
W.D. Dockery, M.D.
Department of Radiology,
1 Silverstein,
Hospital of the University of Pennsylvania,
3400 Spruce Street, Philadelphia,
PA 19104, USA

Present addresses:
R.M. Kowalchuk,
Rochester Radiology Associates,
Rochester General Hospital,
1425 Portland Avenue, Rochester,
NY 14621, USA

R.M. Kowalchuk,
University of Rochester School
of Medicine and Dentistry,
Rochester, NY, USA

Abstract *Objective*. Fast spin-echo (FSE) sequences reduce imaging time compared with conventional spin-echo (CSE) sequences, but may result in blurring. High-performance gradients permit shorter interecho spacing and use of the second echo as the effective TE (20 ms); both improvements reduce blurring. This randomized observer study compared a short TE, second-echo FSE sequence obtained using high-performance gradients and a CSE sequence with similar TR/TE for the detection of meniscal tears in the knee.
Design and patients. One hundred consecutive MR examinations of the knee using FSE and CSE sequences at 1.5 T were evaluated. The FSE sequence used an effective TE of 20 ms (centered on the second echo at 2 times minimal interecho spacing) and an echo train length of 4. FSE and CSE parameters were otherwise similar. Four independent, masked readers reviewed randomized sagittal FSE and CSE sequences.
Results. Cases were assessed for the presence or absence of meniscal tears and, if present, whether tears were medial or lateral and anterior or posterior. Sequence concordance was 93.5% (1496 of 1600 meniscal segments); the intermethod kappa value was 0.78. Sequence quality was graded from 1 to 5. Average quality of CSE images was slightly but statistically significantly preferred by three of the four readers.
Conclusion. There was no statistically significant difference between CSE imaging and FSE imaging centered on the second echo (20 ms) using high-performance gradients for the detection of meniscal tears in the knee. There was a small preference for the quality of CSE images.

Key words Magnetic resonance imaging, comparative studies · Knee, menisci · Knee, MRI · Meniscal tears

Introduction

The use of conventional spin-echo (CSE) MR imaging of the knee has been well established as an accurate technique in the diagnosis of meniscal tears [1, 2, 3]. Although fast spin-echo (FSE) imaging takes less time than CSE imaging, the use of short echo times (TE) may result in blurring [4, 5]. Several authors have compared FSE imaging with CSE imaging to determine whether FSE could decrease examination time without sacrificing diagnostic accuracy, but there has been considerable disagreement as to the diagnostic equivalence of the two sequences [6, 7, 8, 9].

In an effort to resolve this controversy, we have utilized FSE imaging with high-performance gradients. These high-performance gradients permit shorter interecho spacing and the use of the second echo as the effective TE with echo times sufficiently short (20 ms) that only minimal T2 weighting occurs. Both the use of shorter interecho spacing and the use of the second echo rather than the first echo as the effective TE decrease blurring [5]. This randomized observer study compared a short TE FSE imaging sequence obtained with high-performance gradients using the second echo as the effective TE with CSE imaging using the same short TE for the detection of meniscal tears in the knee.

Materials and methods

Between February and May 1997, 128 consecutive MR examinations of the knee which included both sagittal short TE FSE and CSE sequences were identified in 122 patients. Twenty-three patients were excluded from the final study population because one or both sequences were either not obtained or obtained with variations in the imaging parameters, and five patients were excluded due to a known history of prior meniscal surgery. The final study population included 100 examinations in 94 patients; six patients had bilateral examinations. The mean patient age was 40.7 years (range 8–78 years; median 40.5 years). There were 58 male patients and 42 female patients. Arthroscopy results were available in 11 cases; the mean interval from MR examination to arthroscopy was 63.6 days (range 26–158 days; median 49 days).

All patients were imaged at the same institution utilizing a transmit-receive extremity coil (GE Medical Systems, Milwaukee, Wis.) on 1.5-T magnets with high-performance gradients (three “hi-speed” systems with a slew rate of 77 mT $m^{-1}s^{-1}$ and one “echo speed” system with a slew rate of 130 mT $m^{-1}s^{-1}$; gradient strength = 23 mT m^{-1}; Signa, GE Medical Systems). All MR examinations included sagittal short TE CSE and FSE sequences. The CSE sequence was performed using a TR/TE of 1500/23 ms. The FSE sequence was obtained with a TR of 1500 ms and an effective TE of 20 ms (*k*-space centered on the second echo at 2 times minimal interecho spacing) and an echo train length of 4. Because of the need to minimize TE, FSE was performed with a bandwidth of 32 kHz compared with 16 kHz for the CSE sequence; signal-to-noise ratio for the two sequences was maintained equivalent by using 2 acquisitions (i.e., 2 NEX) for the FSE compared with 1 acquisition for the CSE sequence. Parameters for FSE and CSE sequences were otherwise identical: 14–16 cm field of view; 256×192 matrix; and 4 mm section thickness with a gap of 0.5 mm. The FSE sequence was acquired in 2 min 30 s versus 5 min 30 s for the CSE sequence.

For the purposes of this study, four independent readers were presented a masked FSE or CSE sagittal sequence randomized with respect to patient and sequence type. Two readers were experienced musculoskeletal radiologists, one was an experienced MR radiologist with experience in musculoskeletal MR, and one was an MR fellow. No alphanumeric information was displayed, and proctored cases were reviewed on a workstation to avoid pitfalls of photography. Windowing and levelling were performed by the readers. Study cases were reviewed 4–14 months after the studies were performed. For each series, readers were asked to determine whether a meniscal tear was present or absent; if present, readers localized tears as involving anterior and/or posterior horns of either meniscus. The following scale was used: 1, definitely normal; 2, probably normal; 3, possibly torn; 4, probably torn; and 5, definitely torn. For purposes of statistical evaluation, menisci scored “1” or “2” were considered not torn while those scored “3”, “4” or “5” were considered torn. Standard criteria were applied for the diagnosis of a meniscal tear, namely, increased signal intensity extending to an articular surface [10], deformity, or absence of the meniscus. Overall quality of each series was graded from 1 to 5 using the following scale: 1, severely decreased confidence in diagnosis (nondiagnostic image quality); 2, moderately decreased confidence in diagnosis; 3, mildly decreased confidence in diagnosis; 4, diagnostically acceptable; and 5, excellent imaging quality.

Percentage concordance between the FSE and CSE sequences for the interpretation of meniscal tears was calculated. The proportion of tears diagnosed by each sequence was statistically compared for overall agreement with two-tailed asymptotic and exact McNemar’s tests without continuity correction using $P<0.05$ for statistical significance. Segment-by-segment agreement was statistically evaluated with the simple kappa coefficient (SAS, Cary, N.C.; W.J. Montelpare. A webulator for McNemar test and Kappa statistic. @http://arnie.pec.brocku.ca/~wmontelp). A rating scale for kappa values suggests the following correlations for various kappa values: <zero, poor; 0–0.2, slight; 0.2–0.4, fair; 0.4–0.6, moderate; 0.6–0.8, substantial; and 0.8–1.0, almost perfect [11]. Sensitivity and specificity were calculated using arthroscopic correlation in 11 cases, and 95% confidence intervals were calculated [12]. In addition, the sensitivity and specificity of the two sequences were calculated using the other as the reference standard. While not strictly correct statistically, these sensitivity and specificity calculations have demonstrative value and facilitate comparison with the work of Rubin et al. [9]. The quality of the imaging sequences was compared using a two-tailed, paired Student’s *t*-test with $P<0.05$ considered statistically significant.

Results

As shown in Table 1, there was agreement with respect to the diagnosis of a meniscal tear between the FSE and CSE sequences in 1496 of 1600 meniscal segments, or 93.5%. Concordance ranged from 90.8% to 96.3% among the four readers. The proportion of tears diagnosed by each sequence was not statistically significantly different according to McNemar’s test (0.783; $P=0.695$). The kappa value for the pooled data was 0.784, ranging from 0.713 to 0.839 among the readers, indicating substantial to almost-perfect agreement.

Arthroscopic correlation was available in 11 cases. In these cases, the readers had a sensitivity of 89.3% (95% confidence interval: 72.8–96.3) with a specificity of 88.5% (82.4–92.7) for the diagnosis of meniscal tear in a particular horn with the FSE sequence, and 96.4%

Table 1 Concordant diagnoses of tear versus no tear for multiple readers between fast spin-echo and conventional spin-echo sequences (*n*=100 for each reader and each horn; *AHMM* anterior horn medial meniscus, *PHMM* posterior horn medial meniscus, *AHLM* anterior horn lateral meniscus, *PHLM* posterior horn lateral meniscus)

Reader	AHMM	PHMM	AHLM	PHLM	Total[a]	Kappa[b]
1	96	93	94	80	363 (90.8)	0.713 (0.626–0.799)
2	95	95	97	95	382 (96.3)	0.839 (0.766–0.911)
3	97	94	93	89	373 (93.3)	0.790 (0.714–0.866)
4	98	91	98	91	378 (94.5)	0.800 (0.720–0.881)
Subtotals	385	373	382	355	1496 (93.5)	0.784 (0.743–0.823)

[a] Numbers in parentheses are percentages
[b] Numbers in parentheses are 95% confidence intervals

Table 2 Comparison of fast spin-echo (*FSE*) and conventional spin-echo (*CSE*) sequences using each other as the gold standard (*TP* true positives, *TN* true negatives, *FP* false positives, *FN* false negatives)

Reader	Gold standard: CSE						Gold standard: FSE	
	TP	TN	FP	FN	Sensitivity	Specificity	Sensitivity	Specificity
1	62	301	23	14	81.6	92.9	72.9	95.6
2	58	324	7	11	84.1	97.9	89.2	96.7
3	67	306	12	15	81.7	96.2	84.8	95.3
4	55	323	8	14	79.7	97.6	87.3	95.8
Subtotal	242	1254	50	54	81.8	96.2	82.9	95.9

Table 3 Image quality of fast spin-echo (*FSE*) and conventional spin-echo (*CSE*) sequences

Reader	Mean for FSE	Mean for CSE	*P* value
1	4.30	4.63	<0.0001
2	4.06	4.24	<0.01
3	4.01	4.27	<0.001
4	3.90	3.91	NS

(82.3–99.4) and 89.2% (83.2–93.2), respectively, with the CSE sequence. In one patient, there was apparent disagreement with respect to a tear extending into the body, which three of the four readers considered to extend into the anterior horn but for which there was no arthroscopic mention of an anterior tear; for the purposes of this calculation, these radiological diagnoses were considered false positives.

Comparison of the FSE sequence with the CSE sequence used as the gold standard revealed a sensitivity of 81.8% and a specificity of 96.2%, as shown in Table 2. Conversely, using the FSE sequence as the gold standard, the CSE sequence yielded a sensitivity of 82.9% with a specificity of 95.9%.

The difference in the average quality of the short TE CSE sequence compared with the FSE sequence was statistically significant for three of the four readers, as shown in Table 3; however, the magnitude of the difference was small. For the fourth reader, there was no statistically significant difference between the two sequences when presented in a fashion randomized for patient and sequence type.

A side-by-side comparison of the two sequences in the 11 cases for which arthroscopic correlation was available was also performed by the four readers. In one case, the CSE images were definitely preferred by a single reader; in 24 comparisons, the CSE images were slightly preferred to the FSE images; and in 19 comparisons, there was no preference between the sequences. In none of these 11 cases did a reader prefer the FSE images; however, there were cases in the full image set in which motion or other problems degraded the CSE images and the FSE images were preferred.

Discussion

MR imaging is commonly used for the evaluation of meniscal pathology. The purpose of this study was to determine whether an optimized short TE FSE sequence (obtained in 2 min 30 s) could be substituted for the longer CSE sequence (obtained in 5 min 30 s) without a loss of diagnostic accuracy.

A major disadvantage of FSE imaging is that blurring occurs with short effective TEs, especially with long echo trains, small acquisition matrices, and long interecho spacing [4, 5]. The FSE sequence evaluated in this study utilizes high-performance gradients, which permit the acquisition of images with shorter interecho spacing, thereby reducing blurring. In addition, these gradients allow one to use the second echo as the effective echo time, which still has a sufficiently short TE so that only minimal T2 weighting occurs and so that T2 attenuation of higher-order phase encoding is reduced, thereby also reducing blurring.

We found no statistically significant difference in the diagnosis of meniscal tears between a sagittal short TE FSE sequence using high-performance gradients and the CSE imaging sequence. The kappa value obtained for two of the four readers was at the high end of substantial correlation, while two readers were in the highest range – almost perfect. In addition, there was no tendency of one series to diagnose tears more frequently than the other (Table 2); of the 104 mismatches, 50 diagnosed tears occurred with the FSE and 54 with the CSE sequence; both sequences therefore had similar sensitivities and specificities with respect to each other. For the 11 cases in which arthroscopic correlation was available, sensitivities and specificities were also similar. Lack of perfect concordance between the sequences may relate to intraobserver variability, detection of slightly different tissue characteristics by each sequence, and/or small actual differences between the two sequences.

When imaging sequences were randomized by patient and series type, three of the four readers found a small but statistically significant difference in the average image quality of the proton density FSE compared with the proton density CSE sequences. For the fourth reader, there was no statistically significant difference between the two sequences. A side-by-side comparison of the two

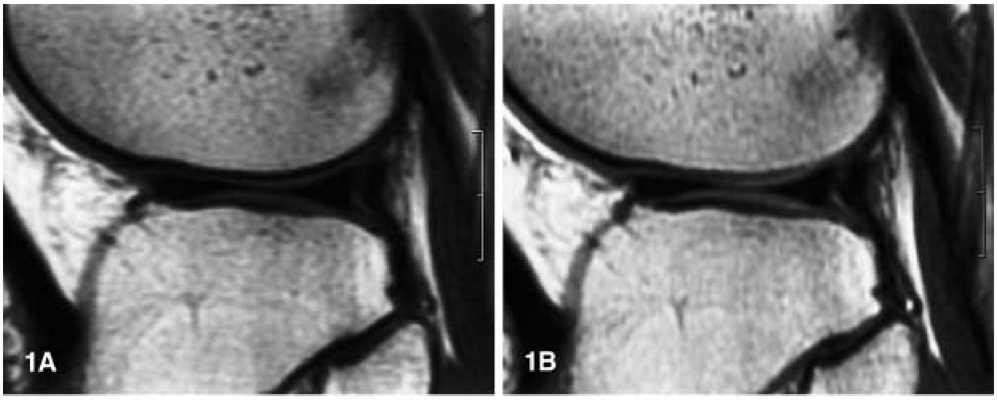

Fig. 1A, B Arthroscopically proven normal lateral meniscus in a 40-year-old woman. **A** Fast spin-echo sequence (TR/TE, 1500/20 ms). All four readers correctly considered this meniscus normal. **B** Conventional spin-echo sequence (TR/TE, 1500/23 ms). All four readers correctly considered this meniscus normal; three readers had no preference between the two sequences while one slightly preferred the CSE image

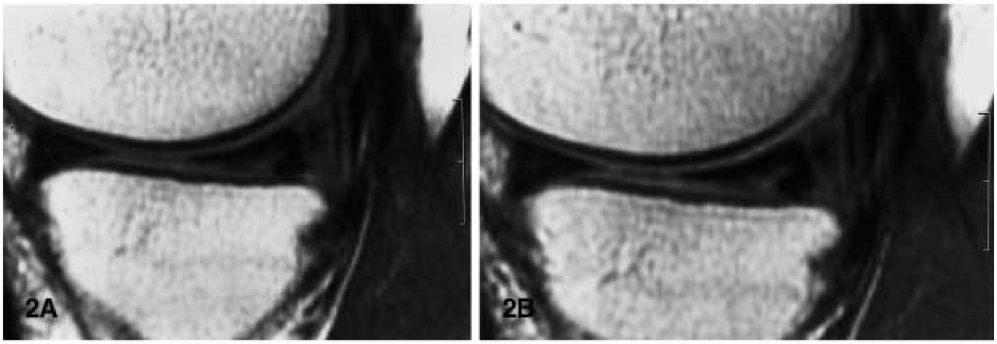

Fig. 2A, B Arthroscopically proven tear in the posterior horn of the medial meniscus in a 60-year-old man. **A** Fast spin-echo sequence (TR/TE, 1500/20 ms). All four readers identified the horizontal tear correctly. **B** Conventional spin-echo sequence (TR/TE, 1500/23 ms). All four readers identified the tear correctly; all readers slightly preferred the CSE image

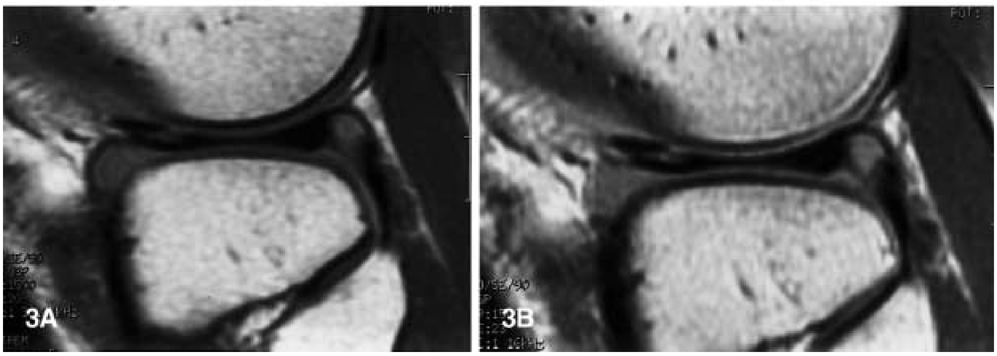

Fig. 3A, B Arthroscopically proven tear of the anterior horn of the lateral meniscus in a 19-year-old man. **A** Fast spin-echo sequence (TR/TE, 1500/20 ms). Three readers identified the tear correctly. **B** Conventional spin-echo sequence (TR/TE, 1500/23 ms). The same three readers identified the tear correctly; two readers preferred the CSE image, while two had no preference

sequences in the 11 cases for which arthroscopic correlation was available suggested that the CSE images were slightly preferred (Figs. 1, 2, 3).

The results of this study, obtained with the use of shorter interecho spacing and the second echo, are an improvement on those of Rubin et al. [9], who obtained a kappa value of 0.62 (calculated from their data) compared with 0.78 in this study. Sensitivity and specificity of the FSE sequence in our study using CSE as the gold standard were 81.8% and 96.2%, respectively, which also compare favorably with respective values of 65% and 96% in that study. It is possible that there have been other technical improvements in FSE imaging since the study of Rubin et al. that may account for some of the improvement. However, it is clear that FSE protocols must be tailored to minimize the blurring which decreases diagnostic accuracy. Direct comparisons with other studies is difficult because of technical differences in sequence acquisition, but sensitivities and specificities for FSE imaging found by Anderson et al. [6], Cheung et al. [7], and Escobedo et al. [8] were 58% (83%) and 83% (75%), 82% and 89%, and 82% and 90%, respectively.

To our knowledge, this study is the largest directly comparing FSE and CSE sequences in the diagnosis of meniscal tears. Another strength of this study is its emphasis on high-performance gradients. In addition, since the four masked readers reviewed cases independently on a workstation, potential differences due to photography were eliminated.

In addition to the time savings achieved with the FSE sequence, one might expect decreased motion artifact and decreased susceptibility artifact. Also, one could trade the time savings for higher signal-to-noise ratio by more signal averages or for improved resolution; we did not attempt to evaluate the utility of these alternate strategies.

A potential limitation of this study is that arthroscopic correlation was available in only 11 cases. However, our goal was to compare the two sequences with each other in consecutive patients with the aim of substituting the faster sequence if diagnostic accuracy was comparable. In addition, we feel that our results are valid because knee MR imaging itself is a highly accurate method of diagnosing meniscal tears [1, 2, 3]. In fact, some have questioned the accuracy of arthroscopy as a gold standard [13]. Finally, given the small percentage of cases for which arthroscopic results were available (approx. 10%), the required patient population for the study would need to be increased approximately tenfold.

Another possible limitation is that only sagittal sequences were compared. However, most tears are well seen on the sagittal images, and there is no a priori reason to anticipate any difference in the relative accuracies of the two sequences between sagittal and coronal planes. Further, the addition of other planes could improve overall diagnostic accuracy, thereby further diminishing any possible differences between the FSE and CSE imaging techniques themselves.

In conclusion, there was no statistically significant difference in the diagnostic ability of conventional spin-echo imaging compared with fast spin-echo imaging using high-performance gradients for the detection of meniscal tears in the knee, and there was a very substantial level of agreement between the two sequences. However, there was a small but statistically significant preference for the quality of CSE images. We expect, but have not proven, that similar results will be seen in other planes and other joints. As a result of this study, we have modified all our musculoskeletal imaging protocols, replacing short TE CSE sequences with short TE, second echo FSE sequences.

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