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Comparison of MR Pulse Sequences in the Detection of Multiple Sclerosis Lesions

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PURPOSE: To compare the sensitivity of conventional spin-echo, fast spin-echo, fast fluid-attenuated inversion recovery (FLAIR), and turbo gradient spin-echo MR sequences in the detection of multiple sclerosis lesions. **METHODS:** Conventional spin-echo, fast spin-echo, fast FLAIR, and turbo gradient spin-echo sequences were performed on a 1.0-T MR imager in seven patients with clinically definite multiple sclerosis. The images in each sequence were evaluated by two raters and consensus was reached by agreement. **RESULTS:** In comparing conventional spin-echo with fast spin-echo sequences, five lesions were seen only by conventional spin-echo and 63 were seen only by fast spin-echo; in comparing conventional spin-echo with fast FLAIR sequences, 18 lesions were seen only by conventional spin-echo and 109 only by fast FLAIR; in comparing conventional spin-echo with turbo gradient spin-echo sequences, 51 lesions were seen only by conventional spin-echo and seven only by turbo gradient spin-echo; in comparing fast spin-echo with fast FLAIR sequences, 45 lesions were seen only by fast spin-echo and 52 only by fast FLAIR. **CONCLUSION:** Fast spin-echo and fast FLAIR sequences improve the sensitivity of MR imaging in the detection of multiple sclerosis lesions with reduced acquisition time as compared with conventional spin-echo sequences. These sequences should therefore be considered for serial studies in patients with multiple sclerosis. The sensitivity of turbo gradient spin-echo was inferior to the other sequences, but its reduced acquisition time could make this technique the ideal choice for patients who cannot tolerate longer examination times.

Index terms: Magnetic resonance, technique; Sclerosis, multiple

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Magnetic resonance (MR) imaging is the most sensitive method for evaluating brain lesions in patients with multiple sclerosis (MS) (1). At present, conventional T2-weighted spin-echo sequences are widely used to monitor disease evolution.

Recently, new pulse sequences have been developed that are characterized by a shorter acquisition time, such as fast spin-echo and turbo gradient spin-echo, or by higher sensitivity, such as fluid-attenuated inversion recovery (FLAIR) (2–4). We examined the sensitivities of these four sequences in detecting MS lesions to determine which sequences are most suitable for monitoring MS lesions.

Subjects and Methods

In the same session, seven patients with clinically definite MS (four with relapsing-remitting disease and three with a secondary progressive MS) underwent MR imaging on a 1.0-T unit. Written informed consent was obtained from all patients before inclusion in the study.

The following sequences were obtained (with a 256 × 256 matrix, a 200-mm field of view, and a 5-mm section thickness): a conventional spin-echo sequence, with parameters of 3000/20–80/1 (repetition time/echo time/excitation), acquisition time of 6:52 minutes, 0% gap, and

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TABLE 1: Comparison of conventional spin-echo (CSE) and fast spin-echo (FSE) sequences

Site	Similar on Both					Only on CSE					Only on FSE					Larger on CSE				Larger on FSE				Total
	1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total	1	2	3	Total	1	2	3	Total	
Posterior fossa	34	3	0	0	**37**	1	0	0	0	**1**	3	1	0	0	**4**	0	0	0	**0**	0	1	0	**1**	**43**
Periventricular	75	24	9	13	**121**	1	0	0	0	**1**	9	0	0	0	**9**	0	0	0	**0**	3	1	1	**5**	**136**
Discrete	67	8	1	0	**76**	3	0	0	0	**3**	4	0	0	0	**4**	0	0	0	**0**	0	0	0	**0**	**83**
Cortical, subcortical	103	11	2	0	**116**	0	0	0	0	**0**	44	2	0	0	**46**	0	0	0	**0**	0	1	0	**1**	**163**
Total	**279**	**46**	**12**	**13**	**350**	**5**	**0**	**0**	**0**	**5**	**60**	**3**	**0**	**0**	**63**	**0**	**0**	**0**	**0**	**3**	**3**	**1**	**7**	**425**

Note.—1 indicates small lesion, diameter <5 mm; 2, intermediate, diameter 6–10 mm; 3, large, diameter >10 mm; and 4, confluent.

27 axial sections; a fast spin-echo sequence, with parameters of 2500/14–85/2, acquisition time of 5:07 minutes, 0% gap, 27 axial sections, and an echo train length of 5; a fast FLAIR sequence, with parameters of 9000/150/1, inversion time of 2200, acquisition time of 2:33 minutes, 100% gap, nine axial sections, and an echo train length of 15—this sequence was repeated to obtain a contiguous set of sections (18 sections, total acquisition time of 5:06 minutes); and a turbo gradient spin-echo sequence, with parameters of 2000/110/1, acquisition time of 0:26 minutes, 100% gap, nine axial sections, and an echo train length of 21.

For the conventional spin-echo and fast spin-echo sequences, the same section positions and orientations were used; for the fast FLAIR and turbo gradient spin-echo sequences, a subset of these section positions was used. Thus, each of the fast FLAIR and turbo gradient spin-echo sections had a corresponding section in both the conventional spin-echo and fast spin-echo sequences. A fast spin-echo sequence was not obtained in one patient.

Data Analysis

All analyses were performed by two of the investigators, who worked together to reduce interrater variability and to simulate as closely as possible the situation in clinical trials. The fast spin-echo, fast FLAIR, and turbo gradient spin-echo images of each patient were compared with the corresponding conventional spin-echo images. In addition, a comparison between fast spin-echo and fast FLAIR images was made. For dual-echo sequences (conventional spin-echo, fast spin-echo), both echoes (proton density–weighted and T2-weighted) were evaluated. When sequences of different numbers of sections were compared, only the sections present on both sequences were included in the comparison.

First, areas of high signal intensity thought to represent lesions were marked on the images and each lesion was scored according to size (1 = < 5 mm; 2 = 6 to 10 mm; 3 = > 10 mm; or 4 = confluent) and assigned to one of the following sites: posterior fossa (brain stem or cerebellum), periventricular (abutting the lateral ventricles), cortical-subcortical (in or immediately adjacent to the cerebral cortex), or discrete (supratentorial lesions away from the ventricles or cortex).

Second, lesions were recorded as similar on the two sequences (ie, present on both sequences and of the same size), present on one sequence and absent on the other, or present on both sequences but larger on one of the two. Differences were recorded only when both observers agreed with a high level of confidence. As in all MS studies, a pathologic correlation of lesions in vivo is almost impossible. It is therefore possible that, occasionally, lesions other than MS lesions were included in our analysis.

Because the data were not normally distributed, the Wilcoxon signed rank test was used to evaluate the differences in number of lesions between two sequences.

Results

Comparison between Conventional Spin-Echo and Fast Spin-Echo Sequences (27 Sections)

Three hundred fifty-seven lesions were seen on both conventional spin-echo and fast spin-echo images (350 of similar size on both types of image, seven larger on fast spin-echo images). An additional 63 lesions were seen on fast spin-echo images only, and five on conventional spin-echo images only. Of these 63 additional lesions, 46 (73%) were cortical-subcortical, thereby increasing the lesions detected in this region (117 lesions) by 39% (163 lesions). Thus, fast spin-echo sequences (total, 420 lesions) showed 58 (16%, $P = .05$) lesions more than conventional spin-echo sequences (total, 362 lesions). Table 1 gives further details about the scores and sites of the lesions.

Comparison between Conventional Spin-Echo and Fast FLAIR Sequences (18 Sections)

Three hundred seven lesions were seen on both conventional spin-echo and fast FLAIR images (293 of similar size on both types of image, two larger on conventional spin-echo images, and 12 larger on fast FLAIR images). An additional 109 lesions were seen on fast FLAIR images only, and 18 on conventional spin-echo images only. Of the 109 additional lesions, 79 (72%) were cortical-subcortical and 19 (17%) were discrete (Table 2). Fast FLAIR images (to-

TABLE 2: Comparison of conventional spin-echo (CSE) and fast FLAIR sequences

Site	Similar on Both					Only on CSE					Only on Fast FLAIR					Larger on CSE				Larger on Fast FLAIR				Total
	1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total	1	2	3	Total	1	2	3	Total	
Posterior fossa	18	2	0	0	**20**	11	0	0	0	**11**	4	0	0	0	**4**	0	0	0	**0**	1	0	0	**1**	**36**
Periventricular	55	20	11	16	**102**	1	0	0	0	**1**	7	0	0	0	**7**	0	0	0	**0**	1	3	1	**5**	**115**
Discrete	53	12	3	0	**68**	3	0	0	0	**3**	17	2	0	0	**19**	0	0	0	**0**	1	2	0	**3**	**93**
Cortical, subcortical	87	14	2	0	**103**	3	0	0	0	**3**	71	8	0	0	**79**	0	2	0	**2**	2	1	0	**3**	**190**
Total	**213**	**48**	**16**	**16**	**293**	**18**	**0**	**0**	**0**	**18**	**99**	**10**	**0**	**0**	**109**	**0**	**2**	**0**	**2**	**5**	**6**	**1**	**12**	**434**

Note.—1 indicates small lesion, diameter <5 mm; 2, intermediate, diameter 6–10 mm; 3, large, diameter >10 mm; and 4, confluent.

TABLE 3: Comparison of conventional spin-echo (CSE) and turbo gradient spin-echo (TGSE) sequences

Site	Similar on Both					Only on CSE					Only on TGSE					Larger on CSE				Larger on TGSE				Total
	1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total	1	2	3	Total	1	2	3	Total	
Posterior fossa	12	0	0	0	**12**	2	0	0	0	**2**	0	0	0	0	**0**	0	0	0	**0**	14				
Periventricular	56	17	5	12	**90**	13	2	0	0	**15**	1	0	0	0	**1**	0	0	0	**0**	0	0	0	**0**	**106**
Discrete	40	6	0	0	**46**	21	0	0	0	**21**	1	0	0	0	**1**	0	1	0	**1**	0	0	0	**0**	**69**
Cortical, subcortical	33	8	2	0	**43**	12	1	0	0	**13**	5	0	0	0	**5**	1	2	0	**3**	0	0	0	**0**	**64**
Total	**141**	**31**	**7**	**12**	**191**	**48**	**3**	**0**	**0**	**51**	**7**	**0**	**0**	**0**	**7**	**1**	**3**	**0**	**4**	0	0	0	**0**	**253**

Note.—1 indicates small lesion, diameter <5 mm; 2, intermediate, diameter 6–10 mm; 3, large, diameter >10 mm; and 4, confluent.

TABLE 4: Comparison of fast spin-echo (FSE) and fast FLAIR sequences

Site	Similar on Both					Only on FSE					Only on Fast FLAIR					Larger on FSE				Larger on Fast FLAIR				Total
	1	2	3	4	Total	1	2	3	4	Total	1	2	3	4	Total	1	2	3	Total	1	2	3	Total	
Posterior fossa	19	2	0	0	**21**	16	0	0	0	**16**	3	0	0	0	**3**	0	0	0	**0**	0	0	0	**0**	**40**
Periventricular	63	15	10	15	**103**	2	0	0	0	**2**	2	0	0	0	**2**	0	0	0	**0**	1	3	0	**4**	**111**
Discrete	54	7	1	0	**62**	11	0	0	0	**11**	3	0	0	0	**3**	0	0	0	**0**	4	0	0	**4**	**80**
Cortical, subcortical	86	20	1	0	**107**	15	1	0	0	**16**	41	3	0	0	**44**	3	0	0	**3**	1	2	1	**4**	**174**
Total	**222**	**44**	**12**	**15**	**293**	**44**	**1**	**0**	**0**	**45**	**49**	**3**	**0**	**0**	**52**	**3**	**0**	**0**	**3**	**6**	**5**	**1**	**12**	**405**

Note.—1 indicates small lesion, diameter <5 mm; 2, intermediate, diameter 6–10 mm; 3, large, diameter >10 mm; and 4, confluent.

tal, 416 lesions) showed 91 (28%, $P = .02$) lesions more than conventional spin-echo images (total, 325 lesions).

Comparison between Conventional Spin-Echo and Turbo Gradient Spin-Echo Sequences (Nine Sections)

One hundred ninety-five lesions were seen on both conventional spin-echo and turbo gradient spin-echo images (191 of similar size on both types of image and four larger on conventional spin-echo images). An additional 51 lesions were seen on conventional spin-echo images only, and seven on turbo gradient spin-echo images only. Conventional spin-echo images (total, 246 lesions) showed 44 (22%, $P = .05$) lesions more than turbo gradient spin-echo images (total, 202 lesions) (Table 3).

Comparison between Fast Spin-Echo and Fast FLAIR Sequences (18 Sections)

Three hundred eight lesions were seen on both fast FLAIR and fast spin-echo images (293 of similar size on both types of image, three larger on fast spin-echo images, and 12 larger on fast FLAIR images). An additional 52 lesions were seen on fast FLAIR images only and 45 on fast spin-echo images only. Fast FLAIR images (total, 360 lesions) showed seven (2%, not significant) lesions more than fast spin-echo images (total, 353 lesions) (Table 4).

Discussion

We compared the sensitivity of conventional spin-echo, fast spin-echo, fast FLAIR, and turbo gradient spin-echo sequences in the detection

of MS lesions. Fast spin-echo and fast FLAIR sequences proved to be significantly more sensitive than conventional spin-echo sequences, and all three sequences were superior to turbo gradient spin-echo sequences in lesion detection.

Comparison between Conventional Spin-Echo and Fast Spin-Echo Sequences

In a previous study comparing conventional spin-echo with fast spin-echo sequences, the number of lesions seen on both sequences was very similar (4). However, about 25% of lesions identified with one sequence were not seen on images obtained with the other sequence. This difference was attributed partially to the intersection gap of 50%, which could account for the loss of lesions as a result of patient movement. Another important factor in that study was the repetition time (3500) used for fast spin-echo sequences, which was higher than that used for conventional spin-echo sequences (2000 and 2700). The cerebrospinal fluid (CSF) therefore appeared brighter on fast spin-echo images, thus possibly masking some immediately adjacent lesions. This might explain why fewer periventricular and cortical lesions were detected on fast spin-echo sequences in that study (4). In contrast, with no intersection gap and more similar repetition times (3000 for conventional spin-echo and 2500 for fast spin-echo), we showed a clear superiority for fast spin-echo sequences. The additional lesions seen on fast spin-echo images in our study were located in all anatomic regions, although the majority (73%) were in cortical-subcortical areas.

Comparison between Conventional Spin-Echo and Fast FLAIR Sequences

In our study, the differences between conventional spin-echo and fast FLAIR images were similar to those between conventional spin-echo and fast spin-echo images, although more accentuated. Compared with conventional spin-echo, fast FLAIR sequences detected 109 more lesions, of which 72% were cortical-subcortical. However, fast FLAIR sequences detected fewer lesions in the posterior fossa than did conventional spin-echo sequences. This finding is of concern, because disabling lesions in MS are more likely to occur in the posterior fossa (5).

Comparison between Fast Spin-Echo and Fast FLAIR Sequences

As compared with the fast spin-echo sequences, the fast FLAIR sequences achieved a moderate increase in sensitivity. However, the anatomic distribution was uneven (Table 4). Because fast FLAIR sequences detected more confluent lesions, it is possible that some of the discrete lesions seen on fast spin-echo images and not on fast FLAIR images were actually present on fast FLAIR images but not counted as separate lesions. Another explanation for the differences between fast FLAIR and fast spin-echo sequences in detecting lesions in the posterior fossa might be that artifacts either blurred some lesions on fast FLAIR images or these artifacts were interpreted as lesions on fast spin-echo images (3, 6).

Properties of Conventional Spin-Echo, Fast Spin-Echo, and Fast FLAIR Sequences

Because they are acquired with a rapid acquisition with repeated echoes (RARE) technique, fast spin-echo and fast FLAIR sequences both have the property that the brightness of structures in the images depends on their size, owing to the point-spread function effect (7). In such sequences, the central part of the data matrix is acquired at the nominal echo time (which is relatively long in our sequences), which increases signal intensity in the outer parts of the data matrix. The result is that small features and edges are emphasized. This might explain the improved detection of small cortical-subcortical lesions on fast spin-echo and fast FLAIR images in our study.

Additionally, the fast spin-echo technique is more sensitive to magnetization transfer (MT)–correlated signal loss than is the conventional spin-echo technique (6). Because MS lesions have lower MT ratios than the surrounding normal-appearing white matter (8), their loss in signal intensity on fast spin-echo sequences is less than that of the normal-appearing white matter, which causes the MS lesions to be more conspicuous. The lesions' greater visibility on fast spin-echo images may be responsible for the increased rate of detection on fast spin-echo as compared with conventional spin-echo images.

In fast FLAIR sequences, the CSF signal is suppressed, allowing a longer echo time and

hence a heavier T2 weighting (9), improving the distinction between the lesion and cortical gray matter, both of which are often isointense on conventional spin-echo and fast spin-echo images (10). Both the suppression of the CSF signal and the longer echo time increase the lesion/CSF and lesion/normal-appearing white matter contrast, which improves the conspicuousness of MS lesions. This explains why more cortical-subcortical and discrete lesions were detected on the fast FLAIR sequences.

Turbo Gradient Spin-Echo Sequences

The decreased contrast-to-noise ratio in turbo gradient spin-echo images is most probably the main reason for the decreased number and size of lesions detected by this sequence as compared with conventional spin-echo imaging. This limitation might be partially overcome by increasing the number of acquisitions.

Conclusions

The increased lesion load detected by fast FLAIR and by fast spin-echo sequences as compared with conventional spin-echo sequences is important. First, it should allow more accurate long-term monitoring of disease evolution. Second, it might improve the correlation of MR imaging results with clinical manifestations of disease, especially cognitive changes (11). Turbo gradient spin-echo imaging, on the other hand, has the benefit of the shorter acquisition time.

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