Original Research

A Comparison of Conventional Spin-Echo and Fast Spin-Echo in the Detection of Multiple Sclerosis

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Fast spin-echo (FSE) pulse sequences enable T2-weighted imaging in a fraction of the time required for T2-weighted conventional spin-echo (CSE) imaging. Due to concerns that the altered contrast characteristics of FSE may interfere with the visualization of multiple sclerosis (MS) lesions, the sensitivity of T2-weighted FSE sequences was compared to comparably weighted CSE sequences in the imaging of the brain in 100 patients with clinically suspected MS. The proton-density FSE sequence revealed more MS lesions than its CSE counterpart, while the T2-weighted CSE sequences were found to be more sensitive than the T2-weighted FSE sequence. Contrast-to-noise ratios and signal-to-noise ratios compared favorably between sequences. Overall, there was little difference in the specificity between FSE and CSE in the diagnosis of MS. The higher sensitivity and the reduction in time attainable through the use of FSE warrants its replacement of CSE when imaging the brain in patients with clinically suspected MS. J. Magn. Reson. Imaging 2001;13: 657–667. © 2001 Wiley-Liss, Inc.

Index terms: multiple sclerosis; spin-echo imaging; fast spin-echo imaging; magnetic resonance imaging; brain

THE FIRST PULSE SEQUENCE to gain wide acceptance in magnetic resonance imaging (MRI) was the conventional spin-echo (CSE) pulse sequence, which is still held today as the gold standard by which other sequences are compared. However, achieving T2-weighted images with CSE has some difficulties associated with it. The primary disadvantage of CSE is the inordinately long scans with low signal averages required when obtaining T2 weighting. Several pulse sequences have been developed in order to resolve this problem, with the most popular sequence to date being the fast spin-echo (FSE) pulse sequence. First proposed in 1984 and further refined in later years (1), FSE has become accepted as a replacement for CSE in imaging the brain when T2-weighted scans are desired, despite the altered signal characteristics that can be attributed to this sequence.

To date, few studies have compared FSE to the standard set by CSE in the detection of multiple sclerosis (MS) lesions (2–5). In each of these studies, a limited number of patients (6, 7, 30, and 18 patients, respectively) was scanned. In addition, a definitive diagnosis of MS had been previously made in each case. Therefore, these studies do not reflect the patient population that is referred for MRI when determining if a patient has the disease. In order to clarify at our site the appropriateness of abandoning CSE for FSE when imaging for MS, we decided to do a direct comparison of CSE with FSE in 100 patients referred with the indication of clinically suspected MS.

MATERIALS AND METHODS

One hundred patients were enrolled in this study and all were referred for MRI of the brain for clinically suspected MS. The first 50 patients were randomly selected prior to imaging. The rationale behind selecting any patient with possible MS was to determine if imaging findings would be present on only one of the two pulse sequences used. The second group of 50 patients was randomly selected from a separate pool of patients who were also referred for MRI of the brain for clinically suspected MS, and had high signal intensity lesions on T2-weighted FSE images. The reason for this was to allow for a comparison of a greater number of lesions between the two pulse sequences.

Each of the 100 patients included in this study was imaged with a 0.5-Tesla GE Signa MRI system (GE Medical Systems, Milwaukee, Wisconsin). The pulse sequences used included a sagittal T1-weighted (TR = 500, TE = 20) CSE sequence followed by an axial proton density and T2-weighted [TR = 3785–4333 msec, TE (effective) = 17–19 msec and 95–102 msec, echo train length (ETL) = 8, 2 signal averages (or number of excitations (NEX)] FSE sequence. To compare with the FSE sequence, an axial proton density and T2-weighted (TR = 2466–2683 msec, TE = 30 msec and 90 msec, 1 signal average) CSE sequence at the same locations was added. In both axial sequences, the slice thickness was 5 mm, interslice spacing was 1 mm, field of view was 22 cm and the acquisition matrix was 256 × 192 (frequency encodes × phase encodes) yielding a spatial resolution of 4.92 mm^3. The time required for the axial FSE sequence was 6:11 (minutes:seconds) to 6:56, while the time required for the CSE sequence was 8:30 to 9:07.

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Table 1a
Signal-to-Noise Ratios Obtained When Comparing Relative Signal Intensities of the Lesion to That of the Background Noise

Patient	PD CSE	PD FSE	T2 CSE	T2 FSE
1	29.21	32.05	22.60	19.18
2	27.62	33.42	21.40	19.18
3	30.52	32.34	27.86	25.19
4	29.19	34.66	26.40	24.78
5	31.43	35.38	21.02	26.25
6	31.08	37.06	23.75	22.24
7	23.91	26.70	17.91	17.07
8	40.45	39.70	43.65	30.79
9	40.47	37.00	40.00	27.81
10	33.38	37.60	28.98	33.02
11	28.19	30.98	22.50	22.31
12	32.60	35.25	28.67	21.44
13	29.12	31.39	20.43	19.28
14	29.33	31.09	20.55	17.75

Table 1c
Signal-to-Noise Ratios Obtained When Comparing the CSF Intensity to That of the Background Noise

Patient	PD CSE	PD FSE	T2 CSE	T2 FSE
1	19.79	26.86	22.00	27.30
2	20.19	29.11	24.65	30.07
3	21.15	26.84	23.41	29.66
4	21.42	32.39	25.30	31.56
5	20.94	28.19	18.88	30.48
6	21.16	30.41	24.30	29.80
7	16.67	23.28	18.82	25.70
8	26.75	30.20	36.31	32.07
9	27.26	30.23	33.25	31.73
10	23.46	30.96	24.20	31.98
11	19.04	28.04	23.63	29.32
12	22.84	31.49	26.46	31.78
13	20.68	27.69	22.24	29.23
14	22.04	28.45	23.90	28.85

All the images were filmed at optimal window width and level. Patient name and pulse sequence parameters were omitted prior to filming and each patient was assigned an identifying number from 1 to 100. Each of the two axial sequences was randomly assigned a letter designation (A or B) for reference by the study administrators (WP, BC). In addition, the T1-weighted sagittal and FSE axial images were filmed with all standard annotations present for reporting by the radiologist.

Study images were reviewed by two radiologists (PC, SL). Cases were mounted in batches of either A or B designated sequences of all the same type of images, either proton density or T2-weighted. In this manner, the reviewers were blinded to patient identity, clinical history, and pulse sequence used.

The reviewers counted the high intensity lesions less than 3 mm in size and greater than or equal to 3 mm in size, and indicated their anatomic location as either posterior fossa, peri-ventricular, cortical/subcortical, or other. If the number of plaques was greater than 10, an average number of 15 was entered to reflect the number of plaques present. This number was arrived at by counting high intensity lesions in a random sampling of patients who had more than 10 lesions. The mean value for lesions in this sample was 14.86, rounded to 15. It was felt to be overly onerous for the reviewers to count all lesions above 10, as the number of lesions above that required to classify a patient as positive for MS were essentially superfluous in regards to the intent of this study. The patients were then classified as positive for MS if they exhibited white matter changes indicative of MS by the criteria set by Paty et al (6) of having three lesions 3 mm or larger, one of which is peri-ventricular. Finally, the reviewers were asked to assess the quality of the images as either good, poor or non-diagnostic. The results were entered into an Excel worksheet (Microsoft, Redmond, Washington) and analyzed by the authors.

Both the contrast-to-noise (CNR) and the signal-to-noise (SNR) ratios were calculated in 14 randomly selected cases where lesions were present (Table 1a–c). SNR was obtained by measuring the mean signal intensity (SI) of an appropriately-sized region of interest (ROI) over cerebrospinal fluid (CSF), high signal lesions, and white matter, and comparing this to an identically sized ROI over the surrounding air. SNR was calculated using the following formula, using the lesion as an example:

Table 1b
Signal-to-Noise Ratios Obtained When Comparing Relative Signal Intensities of the White Matter to That of the Background Noise

Patient	PD CSE	PD FSE	T2 CSE	T2 FSE
1	20.63	21.30	11.45	8.77
2	21.36	25.47	13.80	11.25
3	20.37	21.26	12.27	10.94
4	21.15	24.84	11.35	9.89
5	22.76	24.95	10.19	11.43
6	21.36	25.09	12.40	10.70
7	17.13	19.87	10.27	9.02
8	27.90	24.32	19.92	12.08
9	28.05	24.38	17.29	11.12
10	22.42	23.96	11.93	10.52
11	20.35	22.67	12.80	9.43
12	21.58	25.41	12.41	10.29
13	20.84	22.13	11.19	10.28
14	21.67	23.07	12.00	9.93

Table 1d
Contrast-to-Noise Ratios Obtained When Comparing Relative Signal Intensities of the Lesions and White Matter to That of the Background Noise

Patient	PD CSE	PD FSE	T2 CSE	T2 FSE
1	8.58	10.75	11.15	10.41
2	6.26	7.96	7.60	7.93
3	10.15	11.08	15.59	14.26
4	8.04	9.82	15.05	14.89
5	8.67	10.43	10.83	14.82
6	9.72	11.97	11.35	11.54
7	6.78	6.83	7.64	8.05
8	12.55	15.39	23.73	18.70
9	12.42	12.63	22.71	16.70
10	10.96	13.64	17.05	22.50
11	7.85	8.31	9.70	12.88
12	11.02	9.84	16.26	11.16
13	8.28	9.26	9.24	9.00
14	7.67	8.02	8.55	7.82

Table 1e
Contrast-to-Noise Ratios Obtained When Comparing Relative Signal Intensities of the Lesions and CSF to That of the Background Noise

Patient	PD CSE	PD FSE	T2 CSE	T2 FSE
1	9.42	5.18	0.60	−8.11
2	7.43	4.31	−3.25	−10.89
3	9.37	5.50	4.45	−4.47
4	7.77	2.27	1.10	−6.78
5	10.49	7.18	2.13	−4.23
6	9.92	6.65	−0.55	−7.56
7	7.24	3.43	−0.91	−8.64
8	13.70	9.50	7.35	−1.29
9	13.21	6.77	6.75	−3.92
10	9.92	6.64	4.78	1.05
11	9.15	2.93	−1.13	−7.01
12	9.76	3.76	2.21	−10.33
13	8.44	3.70	−1.81	−9.95
14	7.29	2.64	−3.35	−11.10

$SNR_{(lesion)} = SI_{(lesion)}/SI_{(noise)}$. This is the recommended method of measuring SNR from magnitude images (7), but has the potential to underestimate the SNR by as much as 25%. As this paper was striving to directly compare two pulse sequences, it was felt that this underestimation was acceptable as long as both sequences were measured in an identical manner. CNR was calculated using the following formula, using the CNR of lesion to white matter as an example: $CNR_{(lesion\ to\ white\ matter)} = (SI_{(lesion)} - SI_{(white\ matter)})/SI_{(noise)}$, with the signal intensity being measured in the manner described previously.

RESULTS

The proton density-weighted FSE revealed a greater number of lesions than the correspondingly weighted CSE sequence in all areas except when imaging confluent lesions or those 3 mm or greater in size in the peri-ventricular region, and confluent lesions in the cortical/sub-cortical region. The reverse was true when imaging with T2-weighted series, where the CSE sequence allowed for detection of a greater number of lesions than the FSE sequence, with the exception of small lesions (less than 3 mm) in the peri-ventricular area (Table 2).

Table 3a
Number of Cases out of 100 Patients Scanned Positive for MS by Paty's Criteria Listed by Pulse Sequence and Contrast Weighting

Reviewer	PD CSE	PD FSE	T2 CSE	T2 FSE
Observer 1	58	55	54	52
Observer 2	52	57	53	48

Comparing proton density-weighted images in both pulse sequences, a higher SNR was generally obtained with FSE over CSE. However, when comparing T2-weighted images this was only true when the SNR of CSF was being considered. The SNR of both lesions and white matter was, instead, higher on the CSE images.

When comparing the CNR between lesions and white matter on proton density-weighted images, there was higher contrast visualized on FSE scans than on CSE scans (Table 1d).

A comparison of the CNR between lesions and CSF on the proton density-weighted scans revealed higher values for CSE than FSE. When comparing the CNR generated by the same structures on the T2-weighted images, the majority of values recorded for CSE fell very close to the range of values between positive and negative 2, indicating very little contrast was evident. The CNR values for FSE were, in general, significantly negative, reflecting good contrast between lesions and CSF, with lesions being less hyperintense than CSF (Table 1e).

Minor interobserver variability was present in classifying patients as positive or negative for MS using Paty's criteria. Observer 1 classified a greater number of cases as positive for MS on the proton density-weighted CSE sequence while observer 2 rated a higher number of cases as positive for MS on the proton density-weighted FSE sequence. For both observers, the sequence with the lowest positive rate was the T2-weighted FSE (Table 3a). A statistical analysis of interobserver agreement between both radiologists in classifying patients as positive or negative for MS revealed little disagreement with kappa values ranging from 0.799 to 0.959 (Table 3b).

Table 2
Number of High Intensity Lesions Seen in Each Area of the Brain by Sequence and Contrast Weighting, Mean Value Between the Two Reviewers, Standard Deviation in Brackets

Location	PD CSE	PD FSE	T2 CSE	T2 FSE
< 3 mm posterior fossa	21 (16)	41 (32)	36.5 (20.5)	29 (12)
< 3 mm peri-ventricular	294 (136)	352 (74)	283 (72)	290.5 (47.5)
< 3 mm cortical/sub cort.	129 (73)	198.5 (67.5)	164 (100)	132.5 (97.5)
< 3 mm other locations	16.5 (4.5)	22 (7)	18.5 (0.5)	13 (4)
3 mm or greater posterior fossa	93.5 (20.5)	115.5 (16.5)	75.5 (3.5)	70.5 (4.5)
3 mm or greater peri-ventricular	550.5 (57.5)	523 (102)	461 (86)	446 (87)
3 mm or greater cortical/sub cort.	205.5 (31.5)	220 (17)	189.5 (39.5)	137 (31)
3 mm or greater other locations	23.5 (8.5)	34.5 (7.5)	23.5 (2.5)	18.5 (3.5)
Confluent posterior fossa	0 (0)	0.5 (0.5)	0 (0)	0 (0)
Confluent peri-ventricular	17 (3)	7.5 (3.5)	5.5 (1.5)	7 (2)
Confluent cortical/sub cort.	2.5 (1.5)	0.5 (0.5)	1 (0)	0 (0)
Confluent other locations	0 (0)	0 (0)	0 (0)	0 (0)

Table 3b
Kappa Values of Interobserver Agreement by Pulse Sequence and Contrast Weighting

Sequence or contrast weighting	Kappa value
Observer 1 vs. observer 2 PD CSE	0.799
Observer 1 vs. observer 2 T2 CSE	0.940
Observer 1 vs. observer 2 CSE diagnosis	0.878
Observer 1 vs. observer 2 PD FSE	0.959
Observer 1 vs. observer 2 T2 FSE	0.840
Observer 1 vs. observer 2 FSE diagnosis	0.959

In regards to image quality, observer 2 found three cases that contained nondiagnostic images, yet despite this, was able to place the patient in the group positive for MS in two cases, and negative in one, based on the remaining diagnostic images obtained. These were all CSE sequences. Overall, more cases scanned with CSE than FSE were rated poor in quality (Table 4).

DISCUSSION

CSE pulse sequences have long been the standard pulse sequences against which all other sequences are compared, and its ability to demonstrate MS plaques has been well documented (8–11). When comparing the imaging findings present on T2-weighted MRI scans with histopathological samples taken at autopsy, a high degree of correlation was shown (12,13). The sensitivity of CSE in demonstrating MS plaques has been variable with reports ranging from 58% to 80% (11,14), depending on the selection criteria.

The length of time required to obtain a series of T2-weighted images of the brain with CSE is impractical. The standard CSE sequence (TR = 2466–2683 msec) used in this study to achieve T2-weighting required the patient to remain motionless for 8:30 to 9:07. The proton density-weighted image was acquired simultaneously, with no additional time required. In order to achieve T2-weighting with reduced times, several alternative pulse sequences have been devised (1). The most satisfactory to date is the FSE sequence, which approximates the signal characteristics of CSE but with significant reduction in scan time. The time required for the FSE sequence (TR = 3785–4333 msec, ETL = 8) used in this study was 6:11 to 6:56. The proton density-weighted image was obtained at the same time.

FSE is able to accomplish rapid scanning through an alteration of the application of phase encodes over a TR period. This increase in the rate of image acquisition can be applied to imaging patients for MS by either reducing the length of time the patient must remain motionless in the magnet, or by allowing higher resolution scanning with a greater number of signal averages, while still achieving scan times similar to lower resolution CSE sequences (15).

FSE replicates the contrast characteristics of CSE to a reasonable degree. However, there are some notable differences in the resulting image appearance. Fat appears brighter with FSE than with CSE, there is greater blurring of edge definition in the phase direction, both SNR and CNR are altered, and there is increased magnetization transfer (MT) effects (16–18).

This study identified the following five specific areas where CSE and FSE sequences resulted in different findings.

1. Proton density-weighted FSE was found to be more sensitive than proton density-weighted CSE in visualizing lesions less than 3 mm in size.
2. Lesions 3 mm or larger in size were seen better with proton density-weighted CSE when those lesions were peri-ventricular.
3. On T2-weighted scans, CSE demonstrated more lesions than FSE, except when those lesions were peri-ventricular. In this case, FSE was more sensitive.
4. When classifying each case as positive or negative for MS, there was little overall difference in the number of cases classified each way on either sequence.
5. Image quality was judged to be slightly better with FSE than CSE.

1. Proton Density-Weighted FSE Versus CSE, Lesions < 3 mm in Size

We observed a higher sensitivity to small (less than 3 mm) lesions with proton density-weighted FSE than with proton density-weighted CSE images (Fig. 1). When totaling both reviewers' observations, a total of 1227 lesions less than 3 mm in size were reported on the proton density-weighted FSE, while 921 were seen on the similarly weighted CSE, resulting in 33.2% more with FSE.

The higher FSE sensitivity is attributed to a multitude of factors including higher SNR, MT effect, and stimulated echo and diffusion effects. The higher signal characteristic of MS plaques is primarily from fluid, whether it is attributed to expanded extracellular fluid spaces, inflammatory processes, gliosis, or accumulation of intracellular water (12,13,19,20).

Table 4
Each Observer Rated the Quality of the Exam as Either Good, Poor or Nondiagnostic*

Quality	PD CSE		PD FSE		T2 CSE		T2 FSE	
(Observer #)	(O1)	(O2)	(O1)	(O2)	(O1)	(O2)	(O1)	(O2)
Good	98	79	98	85	100	61	100	94
Poor	2	20	2	15	0	37	0	6
Nondiagnostic[a]	0	1	0	0	0	2	0	0

*The first number represents observer 1 while the second number is the second observer's rating.
[a]In all cases classified as "nondiagnostic" the majority of the sequence was diagnostic, but contained selected images that were of sub-optimal quality.

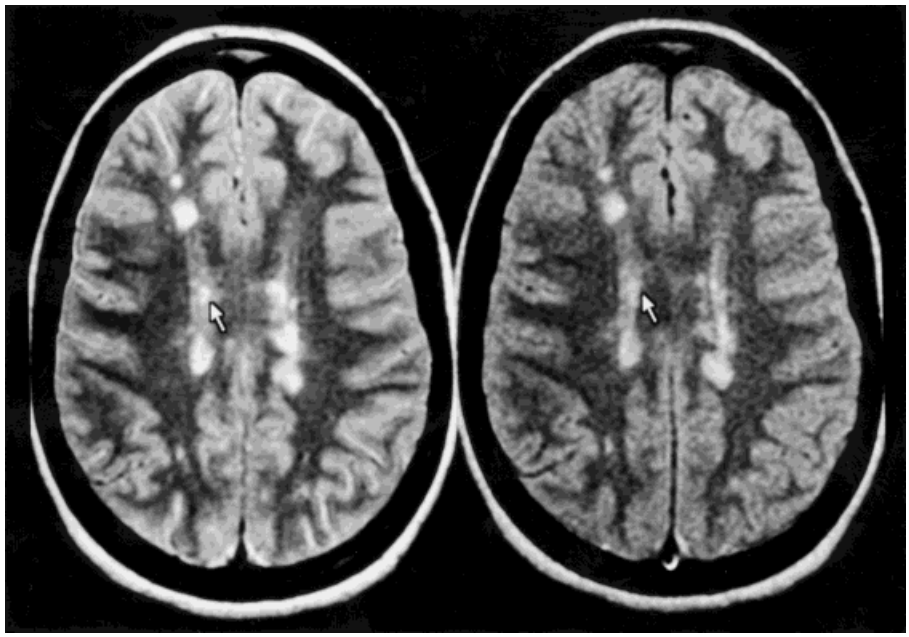

Figure 1. Proton density-weighted FSE (left) and proton density-weighted CSE (right) transverse images of the brain demonstrating small lesions (arrows) better visualized on the FSE sequence.

The increase in SNR of tissues with significant amounts of fluid, such as MS plaques and CSF, with a correspondingly lesser increase in white matter SNR, resulted in a high CNR between the plaques and white matter (Fig. 2). This increased the conspicuity of small MS lesions on FSE sequences (Fig. 3), contributing to the resultant 33.2% increase in the number of lesions reported here.

FSE exhibits an increase in MT effects, which increases the contrast between fluid-containing lesions and the white matter. Diffusion of water between adjacent voxels in each of the slice, phase, and frequency directions may also serve to propagate this effect (3,18,20).

The increase in overall SNR with FSE may also be explained by the contribution of the effects of stimulated echoes. Stimulated echoes occur when three or more RF pulses are delivered in a single TR period. This additional echo in a CSE sequence usually causes image artifacts, but in FSE, the stimulated echo is phase-corrected and incorporated into the received echo. By doing so, there is an overall increase in signal amplitude received, resulting in an increase in SNR (1,18).

2. Proton Density-weighted FSE Versus CSE, Lesions ≥ 3 mm in Size

For all lesions 3 mm in size or greater, proton density-weighted FSE demonstrated a slightly greater number of plaques (1% more). Although this minute difference would indicate that both sequences are equally as good at delineating MS lesions, the sensitivity by location, however, is more revealing.

For all locations except peri-ventricular regions, there was a 14.6% difference between proton density-weighted FSE and CSE (745 lesions were visible on FSE, while 650 lesions were seen on CSE, total seen by both reviewers).

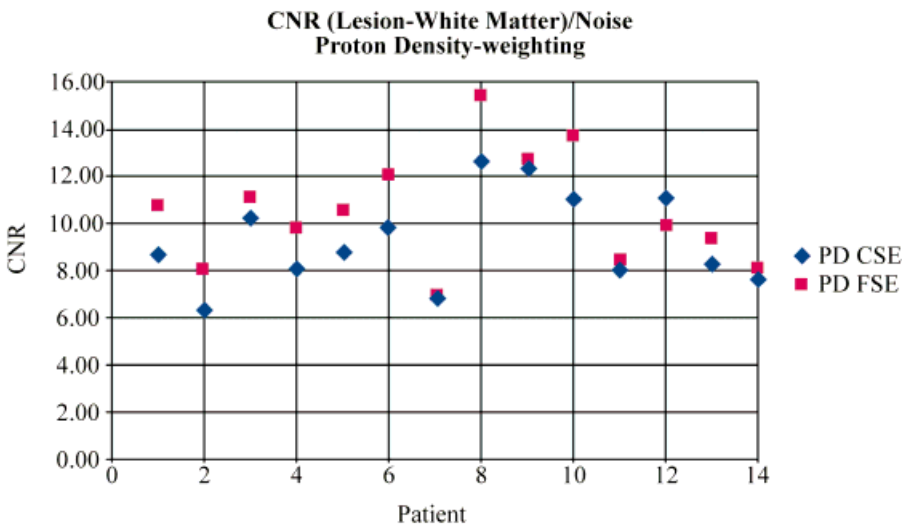

Figure 2. CNR of lesions to white matter on proton density weighted CSE and FSE sequences. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

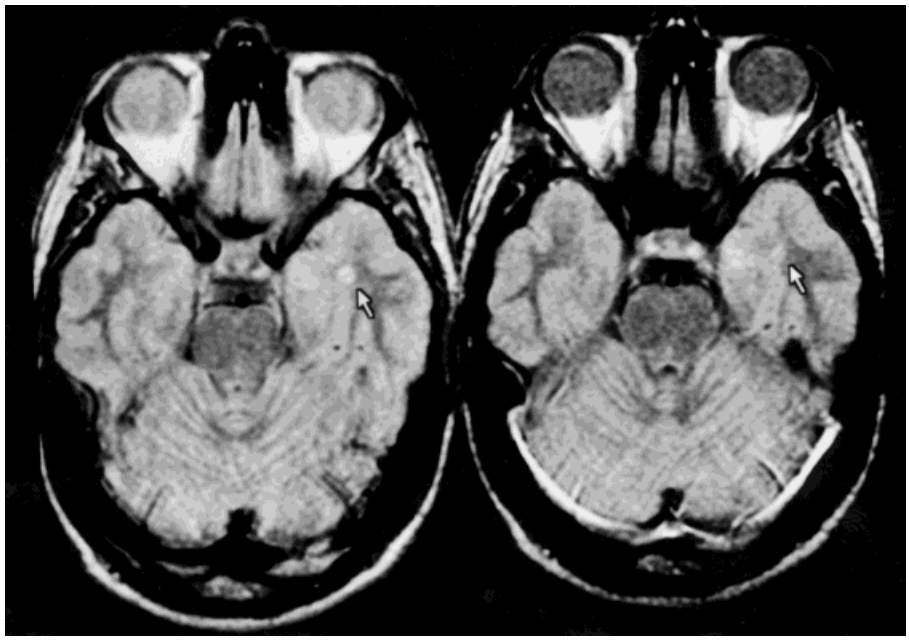

Figure 3. Proton density-weighted FSE (left) and proton density-weighted CSE (right) transverse images of the brain illustrating the increased CNR between lesions (arrows) and the white matter on the FSE sequence.

The reasons for this difference would likely be the same as those discussed above for the smaller (less than 3 mm) lesions. However, when comparing peri-ventricular lesions of 3 mm or greater in size, there was a higher sensitivity for the proton density-weighted CSE sequence over the FSE sequence. In this region, the CSE sequence detected 7% more lesions than the FSE sequence (proton density-weighted CSE revealed 1135 lesions, while proton density-weighted FSE revealed 1061 lesions). This difference can be explained by the better CNR between lesions and CSF on proton density using the CSE sequence compared to FSE (Figs. 4 and 5). The actual distance from the lesion to the CSF will also affect its detectability. If a small lesion is not abutting CSF, yet is still in a position that may be classified as peri-ventricular, it may be more easily seen than a larger lesion with margins in contact with the CSF and, as a result, may be viewed as being incorporated into the ventricles.

3. T2-Weighted FSE Versus CSE, All Lesions

T2-weighted images had a 10% greater sensitivity for all lesions on the CSE sequence (2516 lesions identified on the T2-weighted CSE images, while 2288 were identified on the FSE sequence). If location of plaques was considered, there appeared to be a greater sensitivity to lesions on the CSE sequence in all areas, except for small lesions (less than 3 mm) in the peri-ventricular distribution. In the peri-ventricular area, there was a slightly greater sensitivity with T2-weighted FSE over T2-weighted CSE by 3% (581 lesions visualized on FSE, while 566 were seen on CSE).

The reasons behind this phenomenon are not well understood, but could be partially explained by the higher SNR of lesions and adjacent white matter on CSE than on FSE (Figs. 6 and 7). The higher SNR on the CSE sequence was in part due to changes in the num-

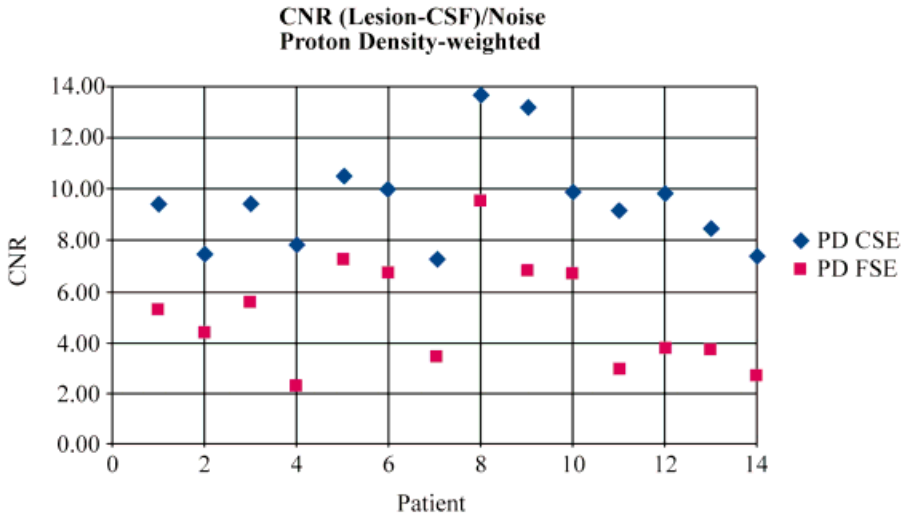

Figure 4. CNR of lesions to CSF on proton density-weighted CSE and FSE sequences. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

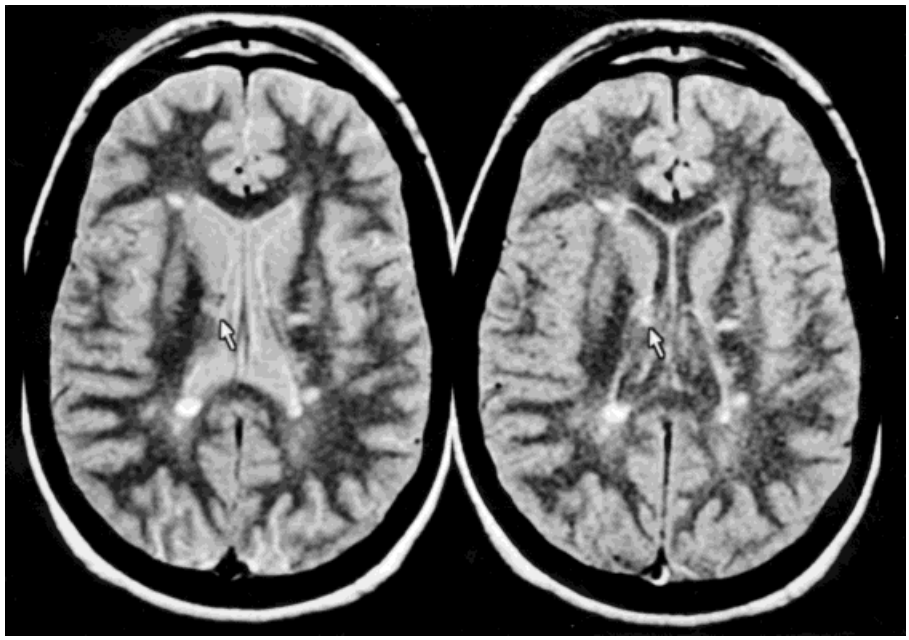

Figure 5. Proton density-weighted FSE (left) and proton density-weighted CSE (right) transverse images of the brain demonstrating the difference in contrast between CSF and lesions (arrows), with greater contrast being evident on the CSE sequence.

ber of signal averages and the receive bandwidth between sequences. The combination of doubling the number of signal averages while increasing the bandwidth from 7.11 KHz to 16 KHz when moving from CSE to FSE resulted in a net loss of 7% in the SNR of the T2-weighted FSE sequence.

When taking the resulting CNR between lesions and white matter into consideration, it became apparent that there was no clear trend between T2-weighted CSE and T2-weighted FSE, with each, at times, being better than the other (Fig. 8). It is possible that the widely varying CNR recorded here is due to the variations in absolute T2 times of MS plaques as they age (21). It is highly probably that all the plaques measured did not represent the same stage of evolution, having differing amounts of T2 decay at the same TE times (Figs. 9 and 10). This, however, does not explain the significant disparity between the sensitivity of the T2-weighted CSE sequence and the T2-weighted FSE sequence, but may account for a portion of the 14.2% decrease in sensitivity seen in the FSE sequence.

4. Classification of Cases as Positive or Negative for MS

The cases were classified as either positive or negative for MS according to Paty's criteria (6). Although there was some variation between reviewers when each echo of each pulse sequence was considered independently (Table 3a,b), no significant differences were present

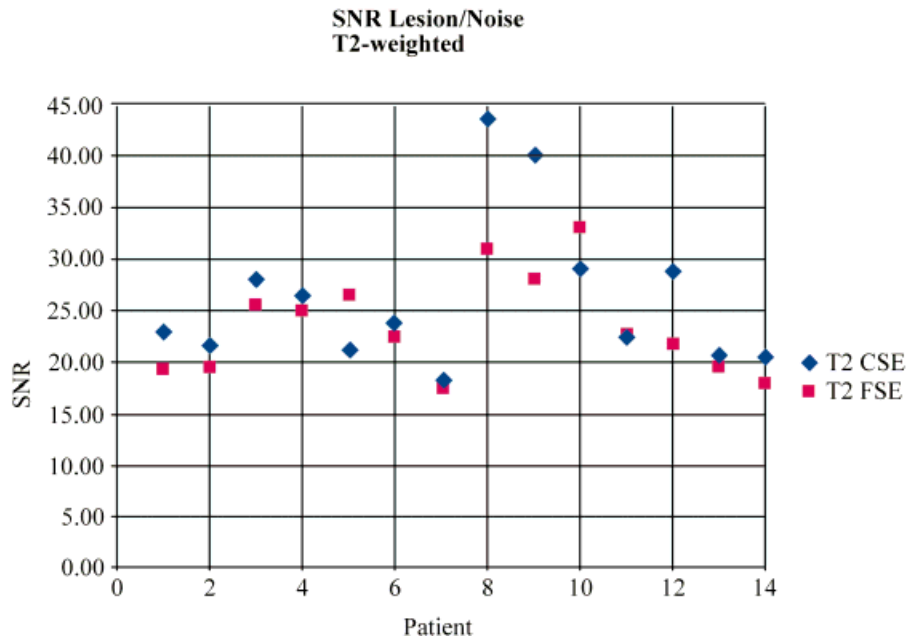

Figure 6. SNR of lesions on T2-weighted CSE and FSE sequences. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

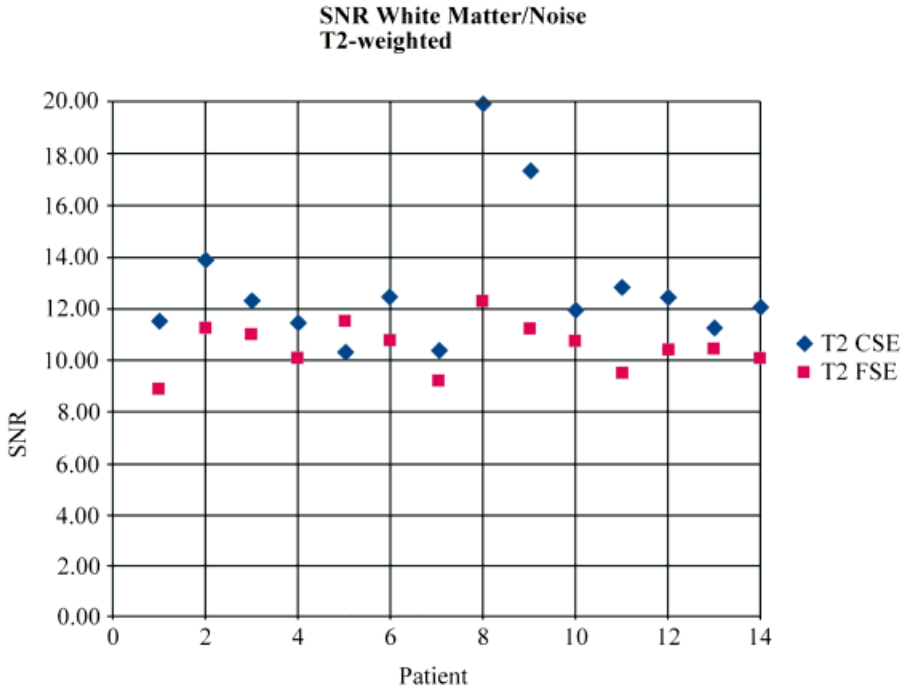

Figure 7. SNR of white matter on T2-weighted CSE and FSE sequences. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

when both echoes of each pulse sequence were considered together. The number of positive cases correlates well to previously published data with similar patient referral criteria (22,23). Furthermore, this minor inter-observer variability did not result in any significant difference in patient diagnosis.

5. Image Quality

The film quality was rated as either good, poor or non-diagnostic (Table 4). There was a higher number of poor exams on the CSE sequence than the FSE sequence. Several factors contributed to this rating, foremost was the quality of filming. There was significant variation in the window width and level settings. Beyond this, there appeared to be greater motion artifact on the CSE sequence. The three most significant factors that contributed to this were the number of signal averages used, the receive bandwidth selected, and the overall length of the scan.

It is well known that the use of multiple signal averages reduces the effects of random noise in an image. Physiological motion that produces noise in the form of ghosting artifacts can also be minimized through the use of the same principle. We refer to this effect as motion averaging. The FSE sequence with 2 NEX would exhibit a 41% increase in motion averaging over the CSE sequence with 1 NEX. As a result, the CSE sequence would be more likely to show the effects of gross patient motion.

As the receive bandwidth is narrowed, the length of time the frequency encode gradient is on, and signal is

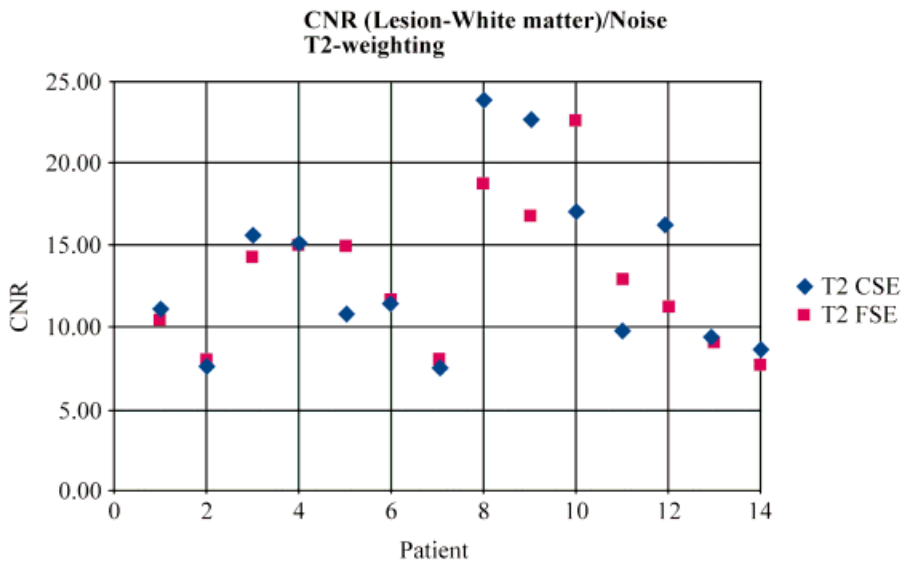

Figure 8. CNR of lesions to white matter on T2-weighted CSE and FSE sequences. [Color figure can be viewed in the online issue, which is available at www.interscience.wiley.com.]

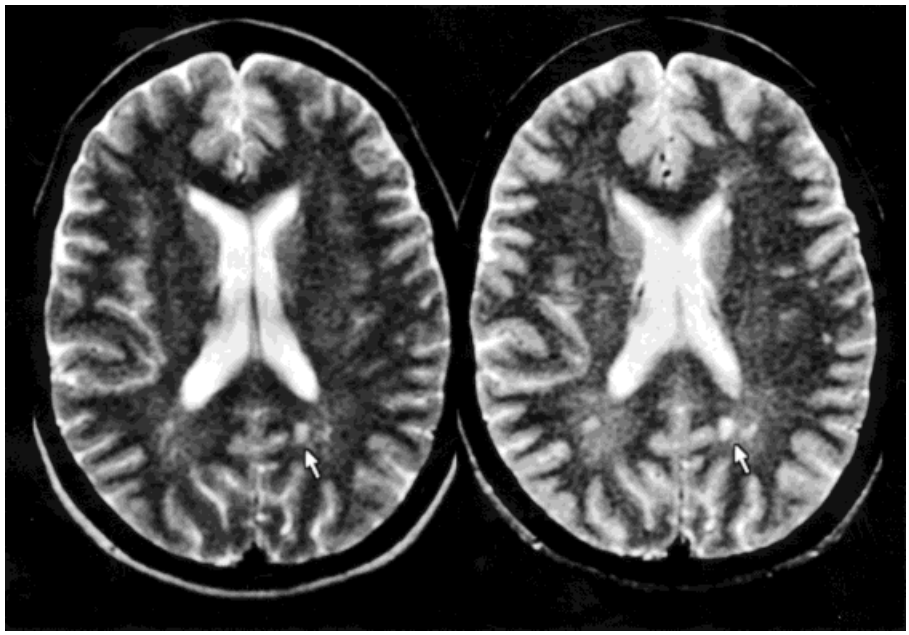

Figure 9. T2-weighted FSE (left) and T2-weighted CSE (right) transverse images of the brain demonstrating a higher CNR between lesions (arrows) and white matter evident on the CSE sequence.

being readout, increases. The FSE sequence having a receive bandwidth of 16 KHz gives less time for patient motion to occur during readout than the CSE sequence with a receive bandwidth of 10.7 KHz (proton density-weighting) or 7.11 KHz (T2-weighting).

Finally, the length of time the CSE sequence took to complete was, on average, 2 minutes and 15 seconds longer than the FSE sequence. Again, this allowed more time for patient motion to occur, thus degrading the images.

Three of the T2-weighted CSE cases contained images that were graded as non-diagnostic. One, which was reported as negative for MS, had images that were filmed at inappropriate window width and window level settings, resulting in overly bright CSF. This could have obscured small lesions in the peri-ventricular region, but would have still allowed the visualization of larger lesions, had any been present. The other two cases were classified as positive for MS despite containing some non-diagnostic images. One had a significant amount of vascular motion on several images. This was felt to be patient dependent, as the identical pulse sequence parameters were used on all patients and this was the only one exhibiting this degree of artifact. The other case had two images that had significant artifact unrelated to the pulse sequence or patient motion. It was thought that these represented transient hardware errors and resulted in a difficulty in determining whether lesions were in existence on those slices. This case was classified as positive based on the number of lesions evident on the remainder of the images.

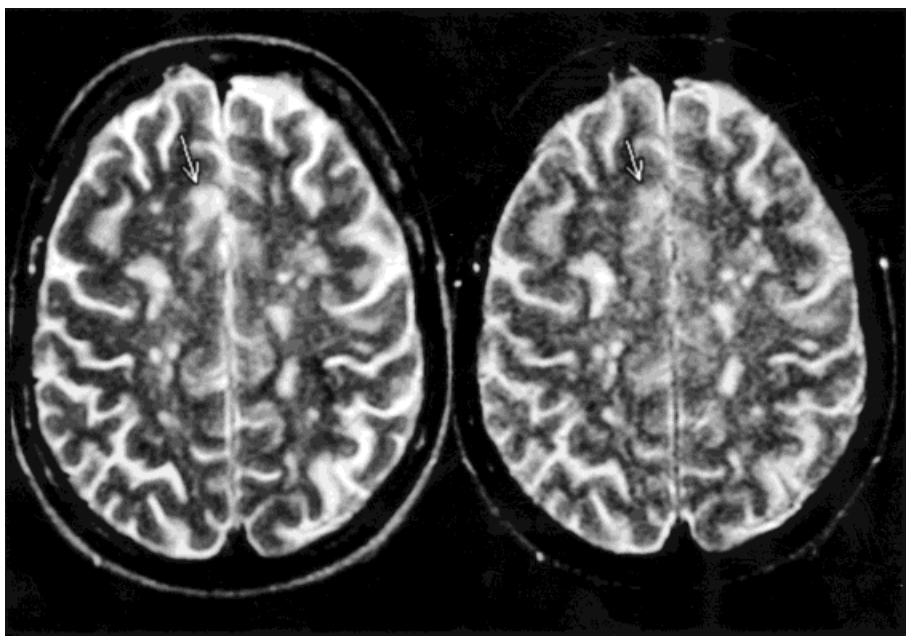

Figure 10. Brain transverse images of T2-weighted FSE (left) and T2-weighted CSE (right) sequences demonstrating better CNR between lesions (arrows) and white matter on the FSE sequence.

Other Imaging Methods

Although the purpose of this paper was solely to compare the sensitivity of CSE with FSE in the detection of MS, we would be remiss to not mention the advent of other sequences that have been shown to have potential in imaging MS. Fluid attenuated inversion recovery (FLAIR) sequences have garnered significant attention over the last few years due to the high contrast ratios attainable between MS lesions and surrounding white matter. Several studies have been done comparing the sensitivity of FLAIR and more conventional sequences. The results have been variable, ranging from limited usefulness dependent on lesion location (4,24–26), to providing a helpful adjunct to conventional imaging when measuring lesion load or activity (27–29).

Diffusion-weighted sequences also have potential in imaging MS lesions. This echo-planar sequence has been shown to be a useful supplementary technique in characterizing MS lesions (31). However, both diffusion-weighted and FLAIR sequences are not readily available on all MRI platforms, thus limiting their widespread use, unlike FSE, which is commonly available.

Another alternative to imaging only with FSE or CSE is the addition of contrast-enhanced T1-weighted CSE sequences. The use of gadolinium in either standard or triple doses has been used to assess both lesion load and lesion activity (4,28–30). In most cases, the highest sensitivity was with this method. However, in the case of a patient referred with the clinical suspicion of MS, it is doubtful that the higher sensitivity justifies the added time and expense of administering gadolinium. In situations where one is measuring lesion load and activity in response to on-going treatment of MS, contrast-enhanced imaging is particularly useful.

CONCLUSIONS

In our patient population referred for MRI of the brain for clinically suspected MS, the use of FSE did not have a significant impact on the classification of the patient as either positive or negative by Paty's criteria for MS. The proton-density FSE sequence allowed for a greater number of lesions to be identified over its CSE counterpart, while the T2-weighted CSE images were found to be more sensitive than the T2-weighted FSE sequence. Since there is little difference in the overall ability to detect clinically significant lesions between the two sequences, and since there is overall better image quality and shorter scan times associated with FSE, we feel it is justifiable to replace CSE sequences with FSE sequences when attaining proton density and T2-weighted images in the brain of those with a clinical suspicion of MS.

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