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BACKGROUND AND PURPOSE: **The T1-weighted fast spin-echo (T1-FSE) MR imaging sequence is not used routinely, since the speed advantage is not as dramatic as it is in T2-weighted imaging. We evaluated the T1-FSE sequence to determine whether this technique can replace the conventional T1-weighted spin-echo (T1-SE) sequence for routine contrast-enhanced imaging.**

METHODS: **Sixty-nine patients with intracranial enhancing lesions underwent both T1-SE and T1-FSE sequences in a random order after administration of contrast agent. Acquisition time was 55 seconds for the T1-FSE sequence and 2 minutes 38 seconds for the SE sequence. The conspicuity of enhancing lesions, peritumoral edema, and gray-to-white matter contrast as well as motion and flow artifacts were analyzed. Signal-to-noise ratios of enhancing lesions, gray matter, and white matter as well as contrast-to-noise ratios (CNRs) of enhancing lesions, with gray matter with white matter as the standard, were calculated.**

RESULTS: **The conspicuity of enhancing lesions was better on T1-FSE sequences than on T1-SE sequences, although the difference in the CNRs of enhancing lesions did not reach significance. Images obtained with the T1-FSE sequence showed less flow and motion artifacts than did those obtained with the T1-SE sequence. The conspicuity of peritumoral edema and gray-to-white matter contrast was lower on the T1-FSE images than on the T1-SE images.**

CONCLUSION: **The T1-FSE sequence reduces imaging time and has the potential to replace the conventional T1-SE sequence for the evaluation of enhancing lesions in the brain when time is a consideration.**

At many institutions, the fast spin-echo (FSE) technique has replaced the conventional spin-echo (SE) technique for routine T2-weighted MR imaging of the brain (1, 2). The FSE technique is faster, decreases the severity of motion artifacts, and allows greater patient throughput. It may also have the potential to improve the detection of enhancing lesions when used for T1-weighted imaging, because greater magnetization transfer (MT) effects produced by multiple applied 180° radio frequency (RF) pulses suppress the signal of the (unenhancing) background tissue (3–5). Despite these assets, however, this technique has not been used routinely for T1-weighted images, as the speed advantage is not as dramatic as it is with T1-weighted imaging (1, 2, 6). We examined intracranial lesions using both contrast-enhanced T1-weighted FSE (T1-FSE) and T1-weighted SE (T1-SE) imaging sequences to determine whether the T1-FSE sequence might replace the conventional T1-SE sequence in the evaluation of lesion enhancement.

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Methods

Patients

Sixty-nine consecutive patients referred for assessment of suspected intracranial lesions were examined prospectively. Nine patients were excluded from the study because no intracranial enhancing lesion was found. Among the remaining 60 patients, 32 were male and 28 were female; the mean age was 41 years (range, 2 to 72 years). Informed consent was obtained in all patients. Histologic verification was obtained in 45 patients with the following disorders: 13 glioblastomas, 11 meningiomas, six anaplastic gliomas, three germ cell tumors, two metastases, and one each anaplastic oligodendroglioma, subependymal giant cell astrocytoma, pilocytic astrocytoma, ependymoma, ganglioglioma, primary cerebral lymphoma, primitive neuroectodermal tumor, acoustic neurinoma, pituitary adenoma, and cerebral abscess. Radiation necrosis in four patients was diagnosed on the basis of radiologic findings, because newly developed enhancing lesions within the irradiated

field disappeared with serial MR examinations. Brain stem gliomas in three patients, dissemination from glioblastoma in one, cavernous hemangioma in one, and multiple sclerosis in two were diagnosed on the basis of typical clinicoradiologic findings. A cerebellar tumor was diagnosed as hemangioblastoma in one patient with von Hippel-Lindau disease. The diagnosis of cerebral lymphoma was obtained in two patients by virtue of a marked decrease in tumor size following steroid therapy. The diagnosis of one meningoencephalitis was obtained by verification of viral infection by CSF analysis.

MR Imaging

MR imaging was performed with a 1.5-T magnet. Parameters for the T1-SE sequence were 690/14/1 (TR/TE/excitations); acquisition time, 2 minutes 38 seconds; number of sections, 19. For the T2-weighted sequence, parameters were 3700/96/1 (TR/TE_{eff}/excitations); echo train length, 7; acquisition time, 2 minutes 7 seconds; number of sections, 19. All images were obtained in the axial plane. To shorten the scan time of the long-TR sequences, T2-weighted imaging was performed with the FSE technique in all patients. If more information was needed, T1-SE or T2-weighted sequences were applied in the coronal or sagittal plane. Then, single-dose contrast-enhanced scans were obtained after intravenous administration of 0.1 mmol/kg gadopentetate dimeglumine. Approximately 5 minutes after injection, both T1-SE and T1-FSE sequences were performed. Parameters for these sequences were 690/12/1 (TR/TE_{eff}/excitations); echo train length, 3; acquisition time, 55 seconds. The number of sections in the T1-FSE sequence was 15, because that is the maximum number of sections allowed with a TR of 690. All sequences used a 265 × 196–224 matrix, a 200- to 220-mm rectangular field of view, and 5-mm-thick sections with a 1-mm gap. To minimize the difference in delayed enhancement effects (7), the postcontrast T1-SE and T1-FSE sequences were performed in random order.

Quantitative Analysis

The signal intensities of enhancing lesions, white matter, gray matter, and background were analyzed quantitatively for each sequence. Standard electronic measurements of signal intensity in each region of interest (ROI) were made by one of the researchers. An ROI was selected from the T1-SE images and a corresponding ROI was found on the T1-FSE images. When patients had more than five enhancing lesions, five lesions were randomly selected. Measurements of signal intensity in the gray and white matter were obtained in areas of the frontal lobe adjacent to the anterior horn of the lateral ventricle and the interhemispheric fissure, respectively. All circle-shaped ROI measurements, varying in diameter from two to 35 pixels, were obtained in the same general location. After the signal intensity of enhancing lesions, gray matter, white matter, and background was measured along the phase-encoding direction (7, 8), signal-to-noise ratios (SNRs) were calculated using the following formula:

$$SNR = SI_{lesion}/N$$

where SI_{lesion} is the mean signal intensity of the ROI within the enhancing lesion and N is the standard deviation of the background.

Contrast-to-noise ratios (CNRs) were also calculated for enhancing lesions and gray matter, with white matter as the standard, using the following formula:

$$CNR = (SI_T - SI_{WM}/N$$

where SI_T is the mean signal intensity of the ROI within the enhancing lesion or gray matter, SI_{WM} is the mean signal intensity of the ROI within the white matter, and N is the standard deviation of the background.

Qualitative Analysis

Two neuroradiologists, who were blinded to the patients' clinical history, evaluated the T1-FSE and T1-SE sequences by consensus. Both images were compared directly for lesion conspicuity using the following grading system: 1 = lesion enhancement more conspicuous with T1-SE, 2 = lesion enhancement equally conspicuous between T1-SE and T1-FSE, and 3 = lesion enhancement more conspicuous with T1-FSE. When peritumoral edema surrounding an enhancing lesion was observed on T2-weighted images, the conspicuity of peritumoral edema was also evaluated with the same grading system.

In a second imaging analysis, two other neuroradiologists, who had no previous knowledge of the cases and who were blinded to the patients' clinical history, individually evaluated the image quality using the following criteria: conspicuity of the gray/white matter junction and magnitude of motion and flow artifacts. To establish a double-blind study, both T1-SE and T1-FSE sequences were numbered randomly and reviewed separately. The conspicuity of the gray/white matter junction was ranked as follows: 1 = poor, 2 = fair, 3 = good, and 4 = excellent. The magnitude of motion and flow artifacts was ranked as follows: 1 = severe, 2 = moderate, 3 = mild, and 4 = none.

Data Analysis

For quantitative analysis, SNRs of enhancing lesions, gray matter, and white matter as well as CNRs of enhancing lesions and gray-to-white matter were obtained. Student's *t*-test was used to compare the difference in SNRs and CNRs between the T1-SE and T1-FSE sequences.

For the evaluation of gray-to-white matter contrast and flow and motion artifacts, the scores of the two observers were calculated for each criterion and these averages were compared between the two sequences using the Wilcoxon signed rank test. A *P* value of less than .01 was considered statistically significant.

Results

All enhancing lesions could be observed on both T1-SE and T1-FSE images. The two sequences were performed in random order, and, as a result, 32 patients initially underwent a T1-SE sequence followed by a T1-FSE sequence and the others initially underwent a T1-FSE sequence followed by a T1-SE sequence. In 34 patients, T2-weighted images showed peritumoral edema surrounding an enhancing lesion, and these were qualitatively evaluated for the conspicuity of peritumoral edema.

Quantitative Analysis

The SNRs of the enhancing lesions were 69.9 ± 22.2 for the T1-SE sequence and 61.4 ± 18.3 for the T1-FSE sequence ($P = .14$); the SNRs of the gray matter were 39.1 ± 9.8 for the T1-SE sequence and 35.2 ± 7.1 for the T1-FSE sequence ($P = .77$). There were no statistically significant differences between the two sequences. The SNRs of the white matter were 44.8 ± 11.1 for the T1-SE sequence and 38.3 ± 7.4 for the T1-FSE se-

TABLE 1: Conspicuity of enhancing lesion and peritumoral edema in 60 patients with intracranial lesions

Conspicuity	FSE > SE	FSE = SE	FSE < SE
Lesion (n = 60)	11	47	2
Peritumoral edema (n = 34)	0	26	8

Note.—FSE indicates T1-weighted fast spin-echo sequence; SE, T1-weighted spin-echo sequence; FSE > SE, the FSE sequence is superior to the SE sequence; FSE = SE, the two sequences are comparable; FSE < SE, the SE sequence is superior to the FSE sequence.

quence. The difference reached statistical significance ($P < .001$).

The CNRs of the enhancing lesions were 22.1 ± 16.9 for the T1-SE sequence and 23.2 ± 14.6 for the T1-FSE sequence. Although the difference did not reach significance ($P = .70$), the CNRs of enhancing lesions were higher on the T1-FSE sequence than on the T1-SE sequence. The CNRs of gray-to-white matter were 5.7 ± 2.6 for the T1-SE sequence and 3.1 ± 2.0 for the T1-FSE sequence. There was a significant difference between the two sequences ($P < .001$).

Qualitative Analysis

In 47 patients (78%), the T1-FSE sequence was ranked equal to the T1-SE sequence for conspicuity of the enhancing lesions, whereas in 11 patients (18%), the reviewers judged the T1-FSE sequence to be superior to the T1-SE sequence (Table 1, Fig 1). The T1-FSE sequence was ranked equal to the T1-SE sequence in 26 patients (76%) in conspicuity of peritumoral edema, whereas in eight patients (24%), the reviewers judged the T1-FSE sequence to be inferior to the T1-SE sequence (Fig 2).

In the qualitative evaluation, gray-to-white matter contrast was significantly poorer on the T1-FSE sequence than on the T1-SE sequence ($P < .001$, Table 2). The results of flow and motion artifacts are listed in Table 3. Although there were no significant differences, the T1-FSE sequence tended to show less severe motion and flow artifacts than did the T1-SE sequence (Fig 3). In a patient with germ cell tumor, metal artifacts associated with surgery were less severe on the T1-FSE sequence than on the T1-SE sequence, and intraparenchymal enhancement adjacent to the metal artifacts was depicted only with the T1-FSE sequence (Fig 4).

Discussion

Acquisition of T1-weighted images with the T1-FSE sequence was only 55 seconds, about one third the time required with the T1-SE sequence. Reduction of imaging time with no sacrifice in the conspicuity of enhancing lesions allows greater patient throughput and may be critical in routine clinical practice, especially for pediatric or uncooperative patients. Additionally, the speed of the T1-FSE sequence can be traded for increased spatial resolution by using larger image matrices while still maintaining short imaging times. Alternatively, one may acquire additional planes without prolonging the total examination time.

The T1-FSE sequence amplifies MT effects because, by increasing the number of 180° RF pulses, the interval between 180° RF pulses is shortened and more gaussian RF pulses, which include some off-resonance frequencies, are applied (5, 9, 10). One report has also documented that MT effects were amplified by increasing the echo train length, which suppressed white and gray matter (11). This MT effect causes relative signal suppression of normal brain tissue, especially white matter, whereas increased signal intensity due to T1 shortening, caused by contrast administration, does not depend on macromolecular interaction and is not appreciably suppressed by MT pulses (5, 10). This technique is considered to be especially useful for detecting enhancing lesions, such as brain metastases or MS plaques (5, 12–15).

Many previous studies have demonstrated the utility of T1-weighted imaging with the MT technique and administration of high-dose contrast ma-

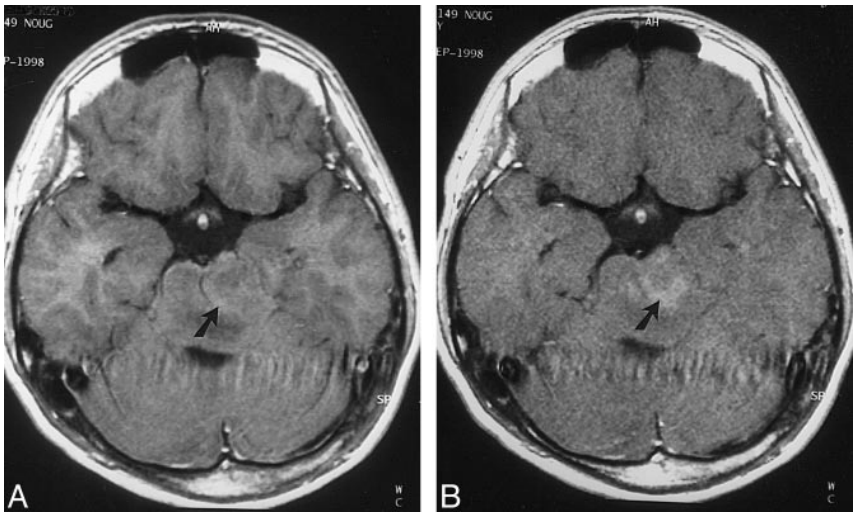

FIG 1. 14-year-old boy with pontine glioma. The T1-FSE sequence was performed before the T1-SE sequence.

A, Enhancing lesion cannot be identified on the T1-SE image (*arrow*).

B, Enhancement is seen within the pons on the T1-FSE image (*arrow*).

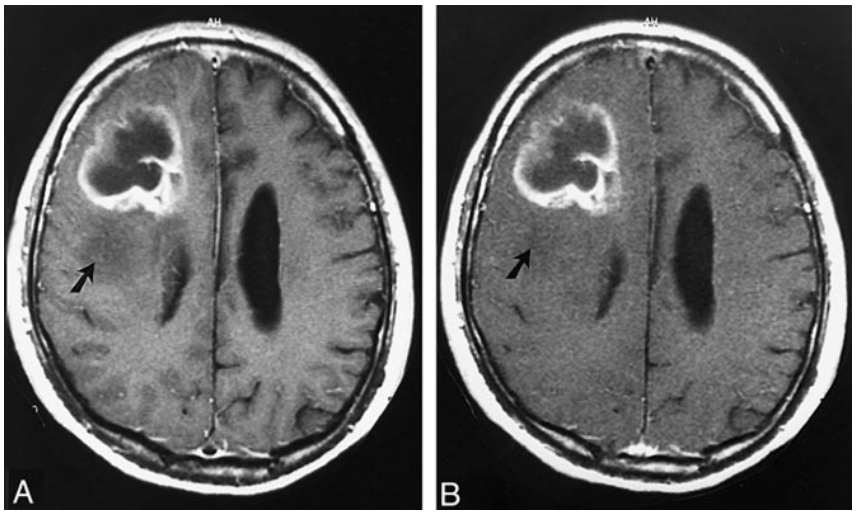

FIG 2. 60-year-old man with anaplastic ganglioglioma. The T1-FSE sequence was performed before the T1-SE sequence.

A, Peritumoral edema is present on the T1-SE image (*arrow*).

B, Peritumoral edema is inconspicuous on the T1-FSE image (*arrow*).

TABLE 2: Qualitative results of gray-white matter contrast

	Poor	Fair	Good	Excellent
Gray-to-white matter contrast				
Spin-echo	10	34	16	0
Fast spin-echo*	48	12	0	0

* $P < .01$.

TABLE 3: Qualitative results of image artifacts

		Severe	Moderate	Mild	None
Flow artifacts					
Spin-echo	$P = .54$	0	2	8	50
Fast spin-echo		0	2	4	54
Motion artifacts					
Spin-echo	$P = .38$	2	22	30	6
Fast spin-echo		2	18	32	8

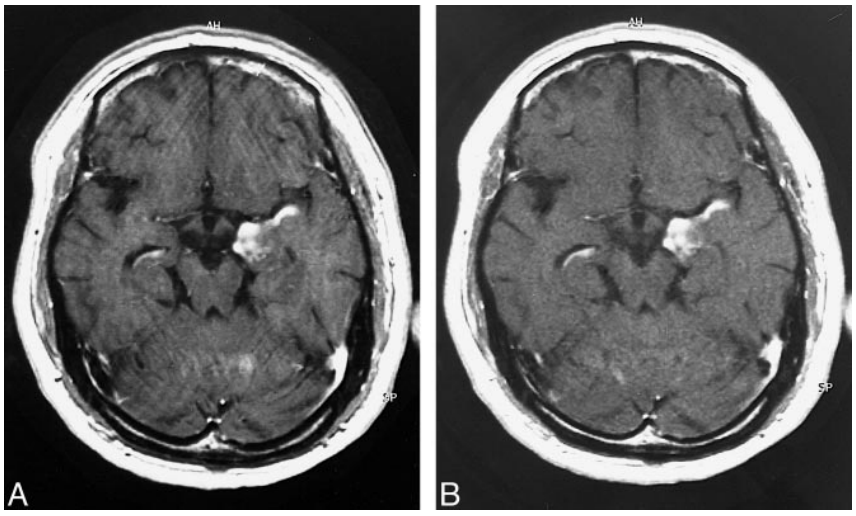

FIG 3. 45-year-old man with glioblastoma. The T1-FSE sequence was performed after the T1-SE sequence.

A and *B,* The T1-SE image (*A*) has more severe motion artifacts than does the T1-FSE image (*B*).

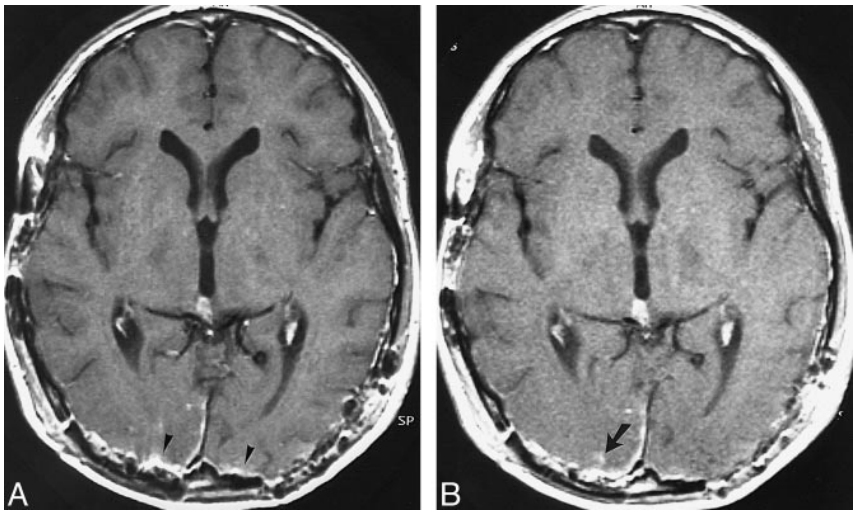

FIG 4. 16-year-old boy with germ cell tumor after surgery. The T1-FSE sequence was performed after the T1-SE sequence.

A, Metal artifacts (*arrowheads*) associated with surgery are present bilaterally in the occipital region on the T1-SE image.

B, Minimal intraparechymal enhancement, which was difficult to identify on the T1-SE image, is clearly depicted on the T1-FSE image (*arrow*).

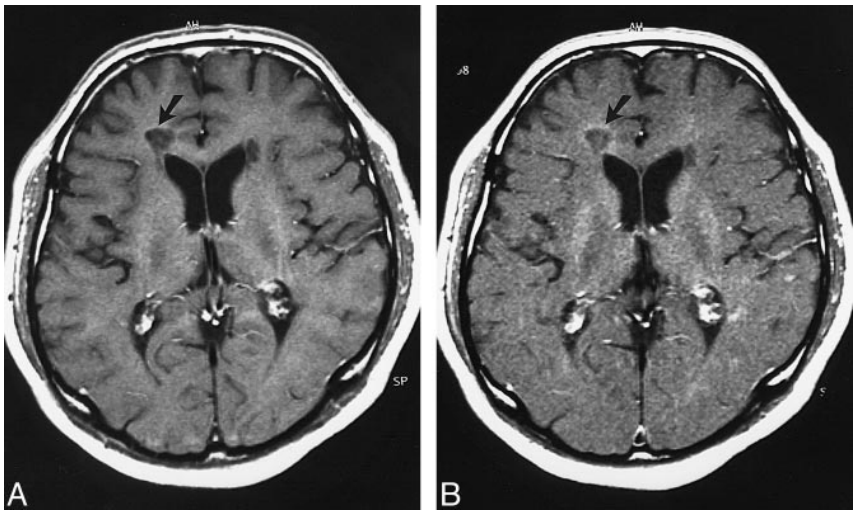

FIG 5. 19-year-old man with multiple sclerosis. The T1-FSE sequence was performed before the T1-SE sequence.

A, On the T1-SE image, multiple sclerosis plaque is observed in right frontal white matter (*arrow*). No apparent enhancing lesion is visible.

B, The T1-FSE image shows hyperintense rim of multiple sclerosis plaque (*arrow*), which was not visible on the T1-SE image.

terial in the detection of enhancing lesions (11–14, 16, 17). However, the conventional MT technique limits the number of sections that can be imaged because an MT pulse is applied before each section-selective excitation in the multisection T1-SE sequence. Although signal suppression of the white matter was more modest with the T1-FSE sequence than with the conventional MT technique (15% vs 26% to 37%), the CNRs of enhancing lesions for the T1-FSE sequence seemed apparent, with higher conspicuity of enhancing lesions on the T1-FSE images. The use of high-dose contrast administration is also unfavorable from the economic standpoint and has the risk of increasing the number of false-positive findings (16). Additionally, relatively longer imaging time can lead to motion artifacts, especially in uncooperative or pediatric patients. The T1-FSE sequence can help overcome these problems.

The MT technique is generally considered to be useful for characterizing MS plaques (5, 12–15, 18). A previous study illustrated that MS plaques can be distinguished from ischemic lesions and edema by measuring MT ratios (19). Other researchers showed that complicated histopathologic conditions can be predicted by calculating the MT ratios (20). Recently, van Waesberghe et al (21) investigated the natural history of enhancing MS plaques and found different patterns of changes in MT ratios, which might predict the evolution of MS plaques. In this study, we encountered a patient with multiple sclerosis in whom the peripheral rim of hyperintensity was inconspicuous on the SE sequence but was easily identified on the FSE sequence (Fig 5). Since we did not obtain a noncontrast T1-FSE sequence, it could not be determined whether the hyperintensity showed enhancement or not. However, this case suggests that the T1-FSE sequence may play a potential role in the characterization of MS plaques.

Recently, rapid pulse sequences using multiple 180° RF pulses, such as half-Fourier single-shot turbo spin-echo (HASTE), have been introduced in the evaluation of brain diseases (8). However, the use of many 180° RF pulses requires a longer TR, which makes it impossible to use those sequences for T1-weighted imaging. Another study showed that the contrast of enhancing lesions was improved

with a combination of FSE and inversion recovery (IR) techniques (17). However, the IR technique also requires a longer imaging time and the relatively longer TR has the risk of reducing T1 enhancement.

One major disadvantage of this technique is the poor contrast of gray-to-white matter and peritumoral edema, which is caused by the differences in suppression of signal intensity by the MT effect (7% for gray matter and 15% for white matter) (5). The placement of early echoes in the center of the k-space to achieve a short effective TE may also lead to poor conspicuity, because image artifacts, such as ringing and image blurring, are produced (22). However, the aim of contrast-enhanced T1-weighted imaging is not to investigate gray-to-white matter contrast or peritumoral edema but to detect enhancing lesions. The T2-weighted images are better than conventional T1-weighted images for evaluation of peritumoral edema.

Another limitation of the T1-FSE sequence is that the maximum number of sections is restricted. The use of a short TR (690 milliseconds) and the multisection technique limited the number of sections to 15. However, 15 sections can almost cover the whole brain. With further development of MR techniques, the above limitations could be overcome in the near future.

Conclusion

The T1-FSE sequence is a fast imaging technique with a potential for replacing the conventional T1-SE sequence in routine MR imaging of enhancing lesions in the brain. A reduction in imaging time allows greater patient throughput, which may be critical in routine clinical practice.

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