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Half-Fourier Acquisition Single-Shot Turbo Spin-Echo (HASTE) MR: Comparison with Fast Spin-Echo MR in Diseases of the Brain

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PURPOSE: To compare an ultrafast T2-weighted (half-Fourier acquisition single-shot turbo spin-echo [HASTE]) pulse sequence with fast spin-echo T2-weighted sequences in MR imaging of brain lesions. **METHODS:** Fast spin-echo and HASTE images of 34 consecutive patients over the age of 50 years or with suspected demyelinating disease were reviewed independently by two neuroradiologists for the number of lesions less than 5 mm and greater than or equal to 5 mm, and for lesion conspicuity, gray-white matter differentiation, and extent of periventricular confluent signal abnormality. The reviewers also assessed for the presence of hemosiderin and extent of motion artifacts. **RESULTS:** Per patient, the mean number of 5-mm or larger lesions detected on fast spin-echo images (1.4) relative to the number detected on HASTE images (0.8) was not statistically significant. For lesions less than 5 mm, fast spin-echo images showed more lesions (7.5) than HASTE images did (2.4). The fast spin-echo images were better at depicting gray-white matter differentiation, conspicuity of lesions, and periventricular signal abnormality. Of four T2 hypointense lesions seen on fast spin-echo images, none was detected on HASTE images. **CONCLUSION:** Although the HASTE technique might be useful for rapid imaging of the brain, our study shows a diminished sensitivity for the detection of lesions less than 5 mm in diameter and for T2 hypointense lesions.

Index terms: Demyelinating disease; Magnetic resonance, technique

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Rapid T2-weighted magnetic resonance (MR) imaging of the brain without the specialized gradient-echo hardware of echo-planar imaging has recently been investigated with the use of hybrid gradient-echo sequences, such as gradient and fast spin-echo (GRASE) pulse sequences (1-4). Potentially, these sequences could be beneficial in rapid imaging of the brain in patients who are claustrophobic or who have difficulty remaining still.

We compared half-Fourier acquisition single-shot turbo spin-echo (HASTE) imaging (Fig 1) with fast spin-echo imaging for sensitivity in

depicting brain lesions by evaluating the number of lesions shown, their conspicuity, gray-white matter differentiation, and extent of periventricular confluent signal abnormality. Because earlier comparative studies have indicated that rapid and conventional studies are equally sensitive in depicting lesions greater than 5 mm in diameter (1, 5, 6), we sought to determine whether the HASTE sequence would demonstrate a similar degree of sensitivity in lesion detection. We also hoped to determine whether the presence of hemosiderin could be detected, since the presence of blood degradation products is useful in characterizing lesions.

Materials and Methods

The subjects for this study were 34 consecutive patients older than 50 years of age or with clinically suspected demyelinating disease who underwent MR imaging of the brain. The age requirement in the absence of suspected demyelinating disease was used to prevent the acquisition of a large number of studies with normal findings; however, only two of the patients were under the age of 50. The

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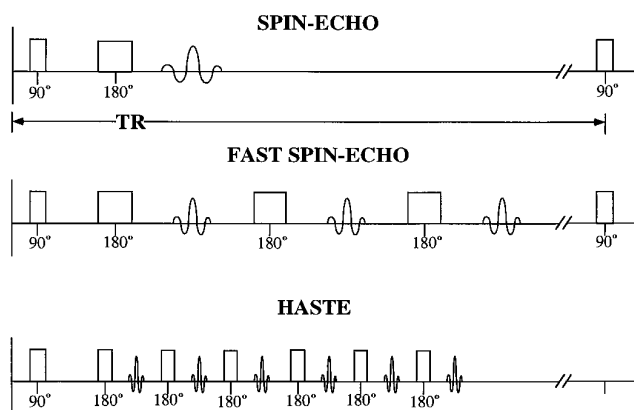


Fig 1. Differences between conventional spin-echo, fast spin-echo, and HASTE imaging shows multiple 180° pulse echoes with a shortened interecho spacing to acquire all the imaging data during a TR with HASTE imaging.

patients included 23 women and 11 men, 34 to 93 years old (mean age, 69 years). Indications for the examination primarily included vascular ischemic signs and symptoms, seizures, demyelination, and metastases.

All patients were examined with a 1.5-T scanner on which a sagittal T1-weighted localizer sequence was obtained, followed by an axial fast spin-echo T2-weighted sequence with parameters of 3600/22,90/1 (repetition time [TR]/effective echo time/excitations) with a section thickness of 5 mm, a matrix of 190 × 256 with oversampling in the frequency domain, and a field of view of 173 × 230 mm. Twenty sections with a 2-mm gap between sections were acquired in an imaging time of 5 minutes 6 seconds. The bandwidth was 130 Hz per pixel, and the interecho spacing was 7 milliseconds. Parameters for the HASTE axial sequence were 4300/60/1, 5-mm section thickness, 192 × 56 matrix, and 265-mm field of view. Twenty sections with a 2-mm intersection gap were obtained in an imaging time of 29 seconds. The bandwidth was 650 Hz per pixel, and the interecho spacing was 4.3 milliseconds.

The fast spin-echo T2-weighted images and the HASTE images were separated and arranged randomly. The images were reviewed retrospectively by two neuroradiologists who were not involved in the original interpretation of the study and who were unaware of the patients' histories. A subjective grading system was used to assess diagnostic usefulness, degree of periventricular change, lesion conspicuity, and gray-white matter differentiation. These characteristics were graded from 0 to 3, with 0 the worst and 3 the best, as detailed in Table 1. As in other studies in which white matter lesions were compared among different imaging sequences (1, 6), we determined the percentage of observations involving a clinically acceptable grade for the parameters of diagnostic utility and gray-white matter differentiation, with a score of 2 or 3 considered clinically acceptable. The final score for each sequence was the average of the two radiologists' grades. These results were then compared by using Wilcoxon's signed

TABLE 1: Definition of qualitative assessment characteristics

Parameter	Value	Definition
Diagnostic utility	0	None
	1	Significantly limited
	2	Acceptable
	3	Excellent
Gray-white matter differentiation	0	None
	1	Barely discernible
	2	Good
	3	Excellent
Periventricular signal	0	None
	1	Minimal
	2	Moderate with confluent areas
	3	Marked
Lesion conspicuity	0	No lesions visible
	1	Barely perceptible
	2	Fairly well seen
	3	Well seen and sharply defined

rank test, with a probability value of less than .05 considered significant. Also, the presence and size of T2 hypointense lesions were assessed, as was the extent of motion artifacts.

The studies were evaluated visually to count the number of lesions that were 5 mm or larger and those that were smaller than 5 mm in maximal diameter. For lesions that did not fall clearly into one category or the other, mechanical calipers were used, and measurements were compared with the centimeter scale on the images. Virchow-Robin spaces, which were identifiable by their typical location adjacent to the anterior commissure and within the cerebral peduncles, as well as by their characteristic appearance, were not considered lesions. Interobserver correlation was assessed by calculating Spearman's correlation coefficient. For analysis, these data were treated separately from the qualitative data above. The two observers then jointly reviewed the studies to achieve a consensus for the number of lesions in each category. This was done to evaluate intersequence differences optimally, not to establish interobserver variability. The results were compared using Wilcoxon's signed rank test. Finally, a side-by-side review of the two sequences was performed to determine the number of lesions seen on both the HASTE and fast spin-echo images, on the fast spin-echo images only, and on the HASTE images only.

Results

Table 2 summarizes the average scores for the qualitative characteristics. The fast spin-echo images were better overall for assessing diagnostic utility, gray-white matter differentiation, periventricular signal intensity, and lesion conspicuity at the $P < .01$ level. The diagnostic utility of the fast spin-echo images (93%) was

TABLE 2: Average score $\pm$ standard error of the mean (SEM) for the subjective characteristics assessed

Characteristic	Fast Spin-Echo	HASTE
Diagnostic utility	2.31 $\pm$ 0.10	1.65 $\pm$ 0.06
Gray-white matter differentiation	2.21 $\pm$ 0.10	0.91 $\pm$ 0.10
Periventricular signal	1.19 $\pm$ 0.14	0.82 $\pm$ 0.13
Lesion conspicuity	2.07 $\pm$ 0.11	1.54 $\pm$ 0.13

Note.— $P < .01$ for all comparisons, Wilcoxon's signed rank test.

TABLE 3: Average number $\pm$ standard error of the mean of hyperintense lesions by size on independent review

Size	Fast Spin-Echo	HASTE	<i>P</i>
<5 mm	7.50 $\pm$ 1.76	2.40 $\pm$ 0.50	<.01
$\geq$ 5 mm	1.39 $\pm$ 0.37	0.80 $\pm$ 0.15	.94

better than that of the HASTE images (60%). Similarly, gray-white matter differentiation was better on the fast spin-echo images (95%) than on the HASTE images (11%).

For evaluation of lesions 0.5 mm in diameter or greater, Spearman's correlation coefficient between the two readers for the fast spin-echo and HASTE images was .723 and .649, respectively, signifying good correlation. For lesions less than 0.5 mm in diameter, Spearman's correlation coefficient was lower: .426 and .557 for the fast spin-echo and HASTE images, respectively. On independent review, averaging each reader's observation, we found no significant difference in the detection of lesions 5 mm or greater ($P = .94$), with an average of 1.4 lesions per patient seen on fast spin-echo images compared with 0.80 lesion per patient seen on HASTE images (Table 3). There was a significant difference in the detection of lesions smaller than 5 mm ($P < .01$), with an average of 7.5 lesions per patient seen on fast spin-echo images compared with 2.4 lesions per patient seen on HASTE images.

A consensus side-by-side review revealed that the HASTE and fast spin-echo sequences were comparable for depicting lesions 5 mm or larger in diameter, and significantly different for depicting lesions smaller than 5 mm. In three patients, no lesions were identified. On fast spin-echo images, 56 lesions 5 mm or greater were detected (Table 4), with an average of 1.6 lesions per patient. On HASTE images, 34 lesions were seen, with an average of one lesion per patient. Twenty lesions 5

TABLE 4: Total number of hyperintense lesions by size detected on fast spin-echo (FSE) and HASTE sequences after a side-by-side review

Size	FSE	HASTE	Either	FSE Only	HASTE Only
<5 mm	273	116	275	159	2
$\geq$ 5 mm	56	34	56	20	0
Total	329	150	331	179	2

mm or greater in size were seen on fast spin-echo images only, while no lesions were seen on HASTE images only. The fast spin-echo sequence was significantly better at depicting lesions smaller than 5 mm, with 273 lesions seen, for an average of 8.0 lesions per patient, whereas HASTE images yielded 116 lesions, for an average of 3.4 lesions per patient. One hundred fifty-nine lesions were seen on fast spin-echo images only, and two lesions were seen on HASTE images only. Figure 2 illustrates the greater number and conspicuity of white matter ischemic lesions on the fast spin-echo images.

Fast spin-echo sequences were better at depicting T2 hypointense lesions, with lesions in four patients visible on the fast spin-echo images that were not seen on the HASTE images. Of these four lesions, two were hemorrhagic infarcts, one was a primary putamenal hemorrhage, and one was a hemorrhage into a probable underlying cavernous angioma. The diminished sensitivity of HASTE images to hemosiderin in a patient with a hemorrhagic infarct is illustrated in Figure 3. HASTE images in one patient resulted in a diagnostic-quality study whereas significant motion compromise was present on the fast spin-echo images.

Discussion

Substantial benefits may be gained from rapid MR imaging of the brain. For one, patient throughput might be increased; for another, image degradation from gross motion artifacts in uncooperative patients or severely ill patients might be diminished. Echo-planar imaging is a highly efficient means of imaging the brain, but there are limitations. The method is sensitive to artifacts from variations in magnetic susceptibility, particularly at air-tissue or bone-tissue interfaces, such as those in the anterofrontal or anteroinferior temporal lobes. Chemical-shift artifacts are severe, requiring homogeneous fat

Fig 2. Evidence of increased number and conspicuity of lesions on fast spin-echo axial MR images.

A, Fast spin-echo axial T2-weighted (3600/90/1) MR image shows small T2 hyperintense foci (arrows).

B, Corresponding HASTE image (4300/60/1) fails to show these lesions well.

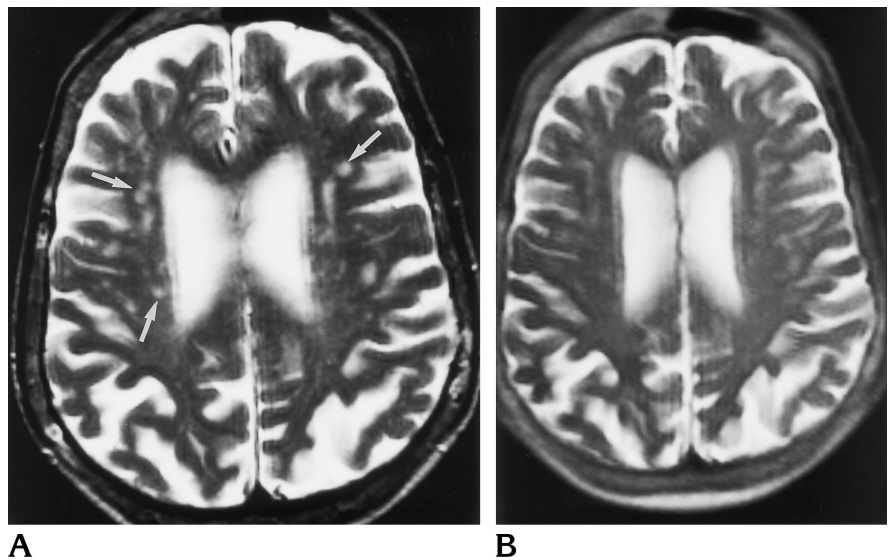
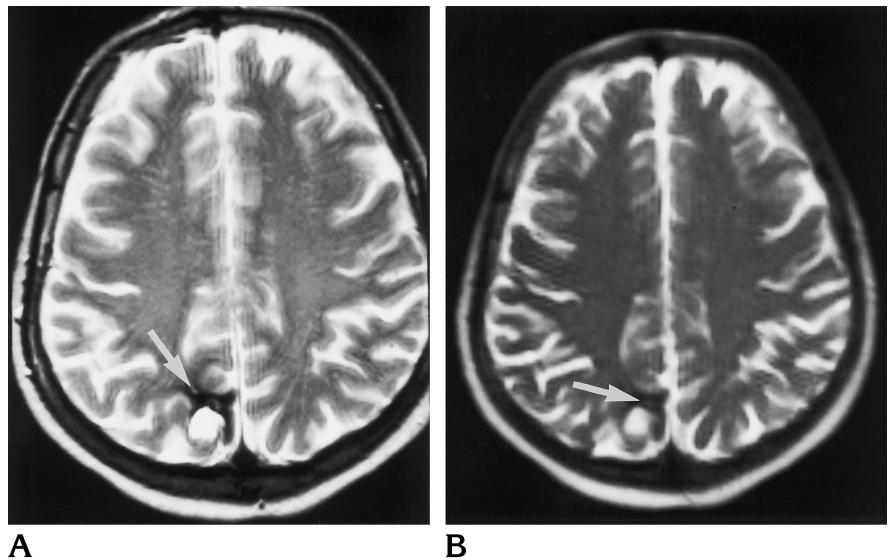


Fig 3. Right parietal lobe hemorrhagic infarct containing hemosiderin.

A, Hemosiderin is seen on fast spin-echo T2-weighted (3600/90/1) MR image (arrow).

B, HASTE image (4300/60/1) fails to show hemosiderin as clearly (arrow).



suppression. Also, the method requires the use of a high-power gradient system, which is not generally available.

Unlike echo-planar imaging, a 128×256 pixel image can easily be acquired with a HASTE sequence, whereas the sensitivity to $T2^*$ relaxation usually limits echo-planar imaging to a 128×128 acquisition matrix. In principle, therefore, HASTE imaging should have twice the spatial resolution of echo-planar imaging for identical fields of view. Some blurring still occurs with HASTE, despite the use of the half-Fourier technique, since the 310-millisecond duration of the echo train exceeds the $T2$ relaxation of most brain tissues (which are on the order of 80 to 100 milliseconds, with the

notable exception of cerebrospinal fluid). If the TR is lengthened, limitations in radio-frequency power deposition or magnetic field gradients will result in more severe blurring artifacts. In a previous study, echo-planar imaging was also less sensitive in detecting demyelinating brain lesions smaller than 5 mm (5).

The basic differences between conventional spin-echo, fast spin-echo, and HASTE sequences are illustrated in Figure 1. Conventional spin-echo sequences acquire one echo, and therefore one line of k-space data, for each TR interval. Fast spin-echo images use additional 180° pulses, typically four to 16 (also known as the echo-train length) within each TR interval, to produce additional spin echoes.

Consequently, they are able to obtain that number of lines of k-space data for each TR interval, thereby decreasing the acquisition by a factor equal to the number of 180° pulses. GRASE images involve a hybrid technique in which several gradient echoes can be obtained between each spin echo, so that a typical sequence might have seven spin echoes and three gradient echoes between each spin echo, to allow the acquisition of 21 lines of k-space data per TR interval. The HASTE sequence uses multiple 180° spin-echo readouts to allow acquisition of slightly greater than one half the k-space data during one TR interval, with the remainder determined by properties of symmetry during image reconstruction. All these sequences can be performed without the need for echo-planar capability, and since all have multiple 180° refocusing pulses, they would be less sensitive to magnetic susceptibility. The contrast of the HASTE images most likely depends on the specific implementation of the sequence, including the image parameters and the specific Fourier transform k-space trajectory, and so, with refinement, further improvement would be expected. This has been demonstrated with the GRASE sequence (3, 7, 8).

The HASTE pulse sequence is a single-shot version of fast spin-echo in which a half-Fourier acquisition is used to reduce the number of phase-encoding steps by nearly a factor of two. The benefit of the shorter echo train is that blurring from T2 decay during the echo train is reduced as compared with the full Fourier acquisition. Assuming a TR of 4.3, the duration of the echo train would be 128×4.3 , or 550. With a half-Fourier acquisition, 64 echoes are acquired plus an additional eight echoes that are used for phase correction, so that the duration of the echo train is considerably shorter, at 72×4.3 , or 310.

Fast spin-echo and HASTE sequences were not statistically different in depicting lesions 5 mm or greater in maximal diameter, although the fast spin-echo sequences did show slightly more lesions. For lesions smaller than 5 mm, HASTE images failed to show 159 lesions, whereas fast spin-echo images failed to show only two lesions. Therefore, the HASTE sequence would not be useful for detecting small lesions, which may be of clinical significance, especially infarcts or demyelinating plaques in critical areas such as the brain stem. Of note, detection of these small lesions did not alter the

initial diagnosis or the clinical management of our patients, at least as far as we were able to ascertain. Also of note, the independent review showed diminished interobserver correlation for detection of small lesions as compared with lesions greater than or equal to 5 mm; we suspect that this interobserver variability in the detection of small lesions is likely to be true for any routine interpretation of MR studies.

Among the four T2 hypointense lesions, none was seen on the HASTE images. This was most likely due to the numerous 180° pulses with a short interecho spacing of 4.3 milliseconds. Obtaining an axial gradient-echo image of the brain would remedy this problem. Since we now use predominantly fast spin-echo imaging of the brain, which also has diminished sensitivity to hemosiderin, we routinely supplement our imaging with gradient-echo sequences. The HASTE sequence we used did not produce appreciable truncation or blur artifacts. As an aside, the diminished susceptibility artifact may be of benefit in postoperative studies of patients who have had spinal fusion or spinal rod placement, as we have had some success in excluding cord compromise in the presence of surgical hardware.

Compared with fast spin-echo imaging, HASTE imaging is at least two orders of magnitude faster. Unfortunately, our results indicate that HASTE imaging cannot replace fast spin-echo in the routine evaluation of the brain, because this technique is insufficiently sensitive to lesions less than 5 mm in diameter. Both HASTE and fast spin-echo imaging are inferior to conventional spin-echo imaging in the detection of hemosiderin in chronic hemorrhages. Nonetheless, HASTE imaging appears to be a reasonable choice for the evaluation of major abnormalities in patients who cannot tolerate longer imaging times.

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