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GRASE (Gradient- and Spin-Echo) MR of the Brain

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PURPOSE: To assess the clinical utility of GRASE (gradient- and spin-echo) MR imaging of the brain by comparing it with the T2-weighted turbo spin-echo technique. **METHODS:** Fifty-three consecutive patients referred for MR imaging of the brain were studied with T2-weighted turbo spin-echo and GRASE techniques, matched for effective echo time (110 milliseconds), echo train length (eight), and spatial resolution. The examinations were evaluated independently by two neuroradiologists for lesion detection (high- and low-signal-intensity lesions) and lesion conspicuity, and for susceptibility, motion, and chemical-shift artifacts. **RESULTS:** The GRASE technique provided greater detection of both high- and low-signal-intensity lesions and of low-signal-intensity lesions with paramagnetic susceptibility characteristics (ie, calcium and hemorrhage). Chemical-shift artifacts in the frequency-encoding direction were more prominent with the turbo spin-echo technique, whereas chemical-shift artifacts in the phase-encoding direction were more prominent with the GRASE technique. There was no significant difference in the degree of diamagnetic susceptibility artifacts at the base of the skull, or in motion artifacts. **CONCLUSION:** T2-weighted GRASE is a fast imaging technique with a potential for replacing turbo spin-echo in routine MR imaging of the brain. GRASE maintains the contrast resolution of turbo spin-echo imaging and is better at depicting lesions with paramagnetic susceptibility characteristics.

Index terms: Brain, magnetic resonance; Magnetic resonance, technique

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At many institutions, turbo spin-echo sequences have replaced conventional spin-echo sequences in routine T2-weighted magnetic resonance (MR) imaging of the brain. Turbo spin-echo imaging is faster and thus decreases motion artifacts and allows for quicker patient throughput. One disadvantage of the turbo spin-echo method in brain imaging is that the multiple trains of radio-frequency (RF) pulses and the short echo spacing used with this technique decrease the conspicuity of susceptibility effects (1, 2), making it more difficult to detect hemorrhagic or calcified lesions as compared with standard spin-echo imaging. Gradient- and spin-echo (GRASE) imaging is a fast multisection MR technique that combines gradient and spin echoes. GRASE makes use of the speed of gradient refocusing while overcoming chemical-shift and field inhomogeneity artifacts (3, 4). We assessed the clinical utility of GRASE in MR imaging of the brain by comparing it with the T2-weighted turbo spin-echo technique. We hypothesized that the gradient-echo component of GRASE would improve the detection of hemorrhagic or calcified lesions while the spin-echo component would maintain the contrast resolution offered by the turbo spin-echo technique. Image artifacts related to both techniques were evaluated.

Materials and Methods

MR Technique

All studies were performed using a 1.5-T superconducting magnet with a peak gradient of 15 mT/m and a quadrature head coil operating in receive mode. Fifty-three consecutive patients referred for brain MR were imaged with axial T2-weighted turbo spin-echo and GRASE techniques, matched for effective echo time (110 milliseconds), echo train length (eight), and spatial resolution. The field of view was 220 cm, the section thickness was 5 mm with a 0.5 mm gap, and the matrix was 256 × 256. For the

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GRASE sequence, three gradient-recalled echoes were generated within successive 180° RF pulses. Image acquisition time for the turbo spin-echo sequence was 2 minutes 47 seconds; for the GRASE sequence, it was 1 minute 17 seconds. For both sequences, the number of signal averages was two. Repetition time for the turbo spin-echo sequence was 3164 milliseconds; for the GRASE sequence, it was 5503 milliseconds. Echo spacing for the turbo spin-echo technique was 15.1 milliseconds; for the GRASE sequence, it was 24.0 milliseconds. Minimum allowable bandwidth was used for both techniques.

Study Design

Two board-certified neuroradiologists, blinded to the patients' clinical histories, reviewed the T2-weighted turbo spin-echo and GRASE images independently. Lesion detection and conspicuity, and susceptibility, chemical-shift, and motion artifacts were graded for each study as follows:

Lesion Detection.—The number of lesions and their location were recorded. Locations were categorized as being either on the left or right side in one of the following areas: cerebellum, cerebral hemisphere, basal ganglia, brain stem, corpus callosum, or extraaxial. Enlarged Virchow-Robbins spaces were noted, but not included in the analysis. Confluent periventricular white matter ischemic changes were also noted, but not graded as individual lesions.

Lesion Signal and Conspicuity.—The detected lesions were then divided into two groups as either low (dark) or high (bright) signal relative to brain parenchyma. Lesion conspicuity was scored on a three-point scale as subtle (0 points), average (1 point), or obvious (2 points).

Artifacts.—Chemical-shift, diamagnetic susceptibility and motion artifacts were graded on a four-point scale as none (0 points), mild (1 point), moderate (2 points), or marked (3 points). Chemical-shift artifacts in the frequency- and phase-encoding directions were evaluated at the globe–orbital fat, skull–cerebrospinal fluid, and scalp-skull interfaces. The degree of diamagnetic susceptibility artifacts at the base of the skull was evaluated in the temporal lobes at the level of the petrous bone and in the frontal lobes just above the orbital roofs.

To standardize the grading of these subjective criteria, the reviewers met before evaluating the images to review the grading systems. An example of each of the grades for each criterion was selected (from images not included in this study) and reviewed by the panel.

Statistical Analysis

A paired *t* test was used to compare GRASE and turbo spin-echo techniques with regard to each of the following seven criteria: the number of high-signal lesions identified in each patient, the number of dark signal lesions, the conspicuity of the dark lesions, the degree of diamagnetic susceptibility at the skull base, the degree of chemical-shift artifacts in the frequency- and phase-encoding directions, and the degree of motion artifacts. The average score of the two observers was calculated for each criterion, and these averages were then used to compare the GRASE and turbo spin-echo techniques.

Interobserver reliability was examined by comparing the results of the two observers for each of the seven criteria. This was done separately for each technique (GRASE and turbo spin-echo) using paired *t* tests.

A two-tailed *P* value of .05 or less was considered significant. No correction was made for multiple comparisons. Because the assumption of a gaussian distribution of the differences in a paired *t* test is questionable, the analyses were repeated with a nonparametric test of significance. The conclusions were identical.

Results

More high-signal (bright) lesions were detected on the T2-weighted GRASE sequences than on the turbo spin-echo sequences ($P <$ .05), for a total of 103.5 on the GRASE sequences and 81.5 on the turbo spin-echo sequences (Fig 1).

More low-signal (dark) lesions were detected with the GRASE technique than with the turbo spin-echo technique ($P <$ .01), for a total of 17 on the GRASE sequences and 10.5 on the turbo spin-echo sequences (Fig 2), (Table 1). The dark lesions were identified in 14 patients by at least one observer; in no case were more dark lesions identified on turbo spin-echo images than on GRASE images. In eight of these cases, dark lesions were detected on both sequences, and scores for conspicuity could thus be compared. Dark-signal lesions were more conspicuous on GRASE studies than on turbo spin-echo studies ($P <$ .05) (Fig 3).

Chemical-shift artifacts in the frequency-encoding direction were more prominent with turbo spin-echo imaging ($P <$ .0001); in the phase-encoding direction, they were more prominent with GRASE imaging ($P <$ .0001) (Fig 4).

There was no significant difference in the degree of diamagnetic susceptibility artifacts at the base of the skull ($P >$ .10), or in motion artifacts ($P >$ .10).

For both GRASE and turbo spin-echo se-

TABLE 1: Average number of lesions detected per patient on T2-weighted GRASE images versus turbo spin-echo images in 53 patients

	High-Signal-Lesions	Low-Signal Lesions
GRASE	1.95	0.32
Turbo spin-echo	1.54	0.20
P	<.05	<.01

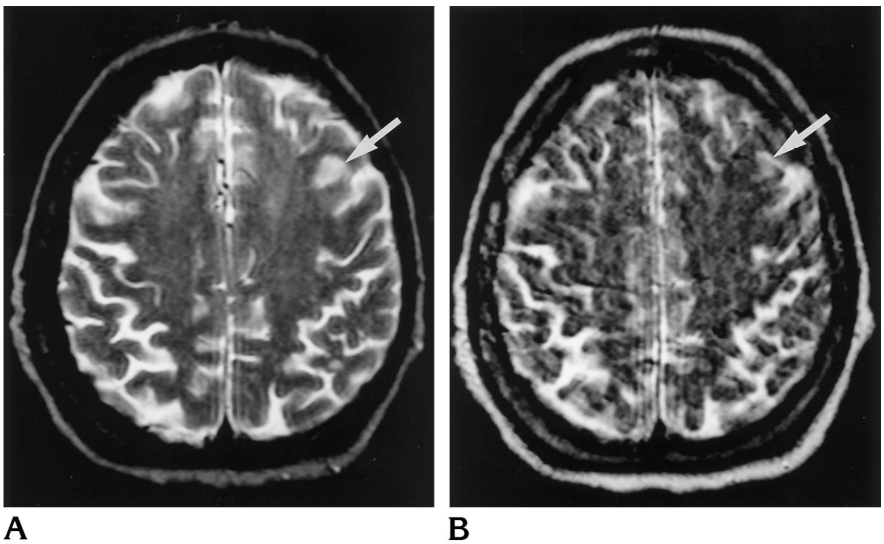


Fig 1. A 75-year-old woman with a change in mental status, diabetes, and hypertension. A lesion of high signal intensity (*arrow*) in the left frontal subcortical white matter is well seen on T2-weighted GRASE image (5503/110/2 [repetition time/echo time/excitations]) (*A*); however, it is much more difficult to identify on T2-weighted turbo spin-echo image (3164/110/2) (*B*).

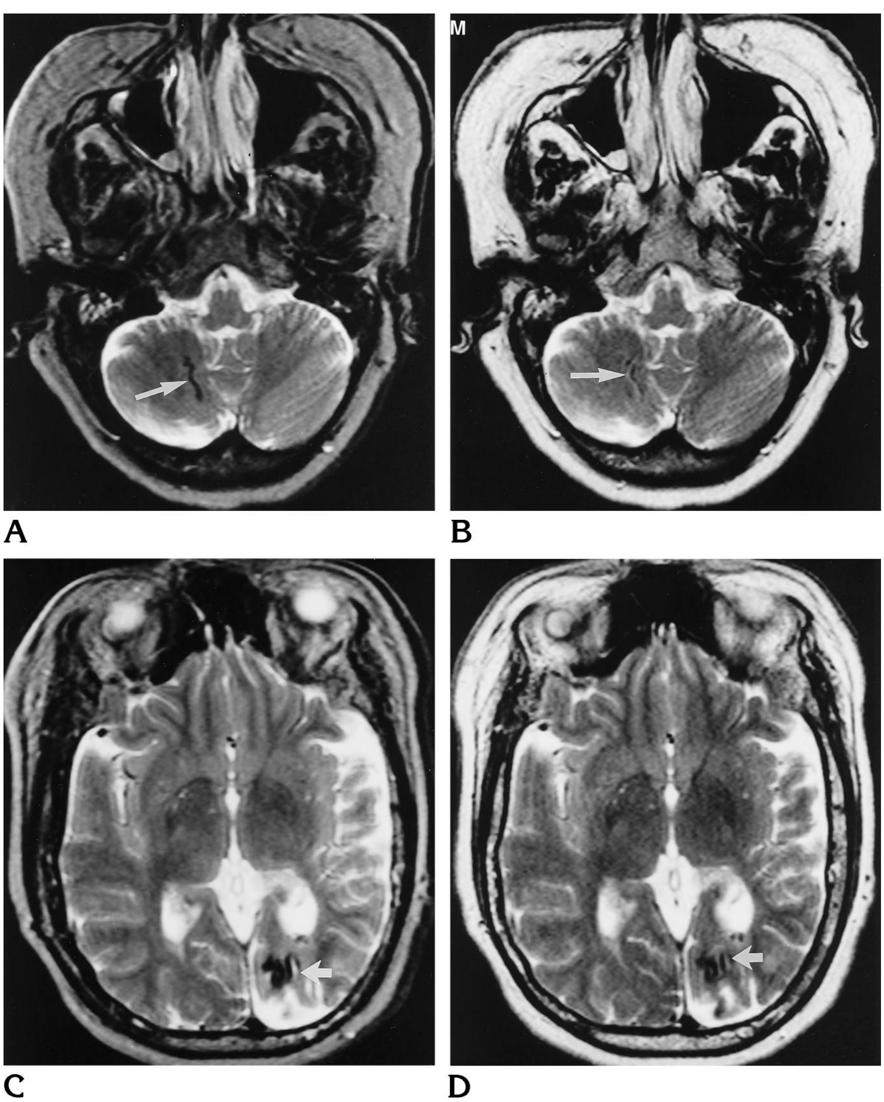
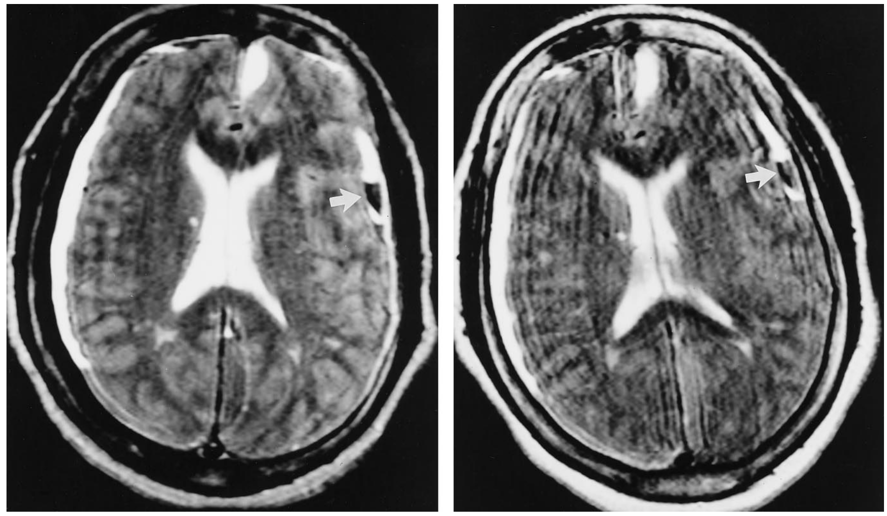


Fig 2. A 34-year-old woman with Sturge-Weber syndrome.

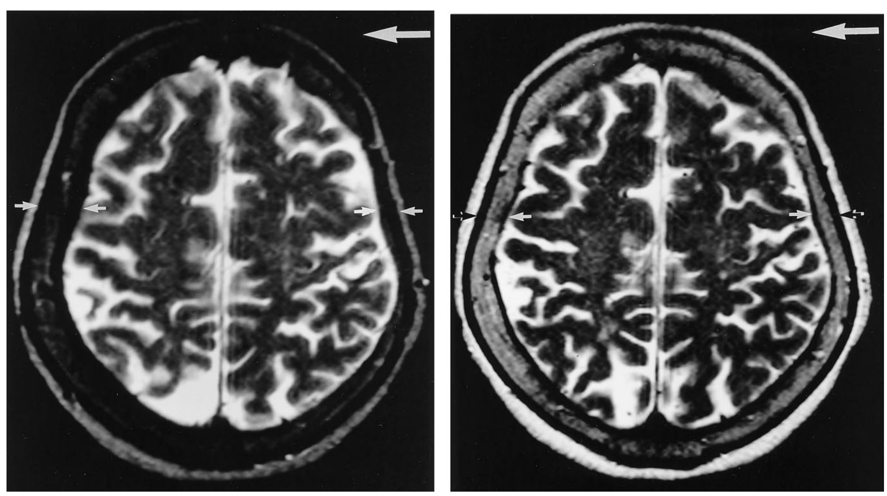
A and *B*, A low-signal, curvilinear calcification (*arrow*) in the right cerebellar hemisphere is well seen on T2-weighted GRASE image (5503/110/2) (*A*); however, it is much more difficult to identify on T2-weighted turbo spin-echo image (3164/110/2) (*B*).

C and *D*, A gyriform calcification in the left occipital lobe (*arrow*) is more conspicuous on GRASE image (*C*) than on turbo spin-echo image (*D*). Note also the lower signal intensity of fat on the GRASE image compared with the turbo spin-echo image.



A B

Fig 3. A 60-year-old woman with bilateral posttraumatic subdural hematomas containing blood-fluid levels. The low-signal in the dependent portion of the left-sided hematoma (*arrow*) is more conspicuous on T2-weighted GRASE image (5503/110/2) (*A*) than on turbo spin-echo image (3164/110/2) (*B*). Note also the reduced motion artifact on the GRASE image relative to the turbo spin-echo image, which is in part due to the faster technique.



A B

Fig 4. A 73-year-old woman with a history of syncope. Chemical-shift artifacts (*small arrows*) in the phase-encoding direction (*large arrow*) are more prominent on T2-weighted GRASE image (5503/110/2) (*A*) than on turbo spin-echo image (3164/110/2) (*B*), as seen at the skull–cerebrospinal fluid and scalp-skull interfaces.

quences, there was no significant difference between the observers with regard to bright- and dark-lesion detection, dark-lesion conspicuity, and motion artifacts ($P > .50$). With GRASE imaging, the only criterion for which a statistically significant difference was noted was for diamagnetic susceptibility at the skull base ($P = .03$). With the turbo spin-echo technique, the only criterion for which a statistically significant difference was noted was chemical-shift artifacts in the frequency-encoding direction ($P = .02$) (Table 2).

Discussion

At many institutions, turbo spin-echo techniques are being used in place of conventional spin-echo for T2-weighted MR imaging of the brain. At our institution, we rarely use conventional spin-echo techniques for routine brain imaging because of frequent problems with patient motion and time constraints. Turbo spin-echo offers contrast resolution similar to spin-echo techniques (5), with a much shorter imaging time. Turbo spin-echo decreases imaging time by acquiring multiple spin echoes during each repetition time interval, resulting in more efficient filling of k-space relative to conventional spin-echo imaging. However, multiple 180° RF pulses and the short echo spacing implemented in turbo spin-echo cause diminished sensitivity to susceptibility effects (1, 2) and in turn reduce conspicuity of intracranial hemorrhagic and calcified lesions as compared with conventional spin-echo imaging.

GRASE is a fast multisection MR technique

TABLE 2: *P* **values for interobserver variability for T2-weighted GRASE versus turbo spin-echo techniques**

	Average Number of High-Signal Lesions Detected	Average Number of Low-Signal Lesions Detected	Conspicuity of Dark Lesions	Artifacts			
				Diamagnetic Susceptibility	Chemical-Shift: Frequency-Encoding Direction	Chemical-Shift: Phase-Encoding Direction	Motion
GRASE	.80	.60	.42	.03*	.26	.08	.13
Turbo spin-echo	.24	.26	.56	.06	.02*	.10	.42

* Statistically significant values.

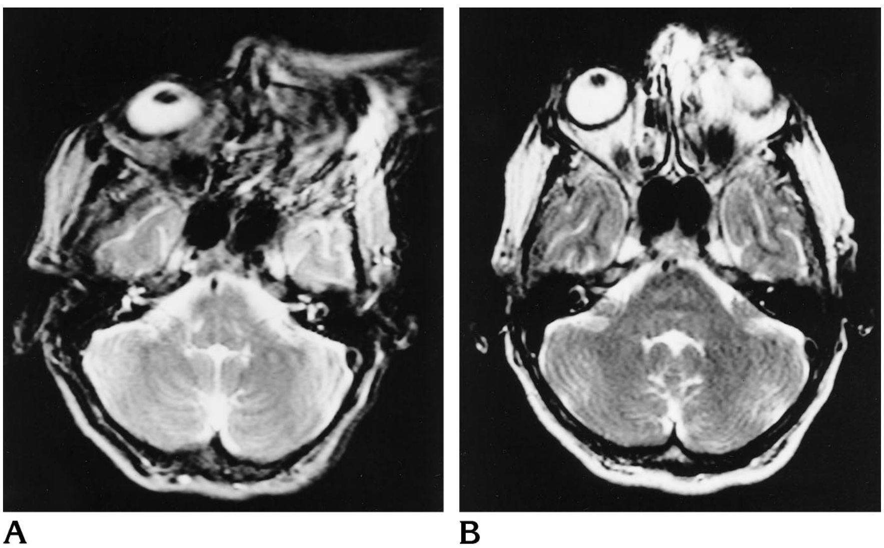


Fig 5. A 68-year-old woman with transient ischemic attacks and fixed metallic dental hardware (braces). The ferromagnetic susceptibility artifact is greater on the GRASE image (5503/110/2) (*A*) than on the turbo spin-echo image (3164/110/2) (*B*), completely obliterating the left orbit.

combining gradient and spin echoes (3, 4). Between successive 180° RF pulses, multiple short gradient-recalled echo trains (three or more) are generated. The total number of signals per repetition time interval is the product of the number of RF refocused pulses (in our case, eight) and the number of gradient-recalled echoes between each (in our case, three). The speed advantage of GRASE over turbo spin-echo is proportional to this latter factor. Thus, one advantage of GRASE imaging is that for a fixed number of RF refocusing pulses, there is decreased imaging time relative to turbo spin-echo. In our study, the image acquisition time for the GRASE sequence was 1 minute 30 seconds faster than for the turbo spin-echo sequence. Another advantage of GRASE is that, at a fixed imaging time, there is less energy deposition to the patients' bodies (3, 4, 6). As with turbo spin-echo, the effective echo time in GRASE is the time at which the center of k-space (zero-order phase encoding) is sampled.

Because of the multiple gradient-recalled echo component of GRASE imaging, we anticipated an increased sensitivity to diamagnetic, paramagnetic, and ferromagnetic susceptibility effects. Gradient-echo imaging is much more sensitive to susceptibility-induced frequency shifts than is spin-echo imaging, because of the lack of refocusing 180° RF pulses (which refocus dephased spins) (7–9). We found an improved detection of paramagnetic lesions, such as hemorrhage or calcium, with GRASE imaging. Not only did GRASE show more dark lesions than turbo spin-echo ($P < .01$) but such lesions were significantly more conspicuous on GRASE sequences ($P < .05$) (Figs 2 and 3).

Because there is a gradient component to GRASE imaging, there is the possibility of unwanted diamagnetic susceptibility artifacts at the skull base. We therefore included this as one of the criteria to be graded in each study to determine whether this would pose a significant problem in clinical imaging. We found there were no greater diamagnetic susceptibility artifacts than with turbo spin-echo imaging ($P > .10$).

Although not specifically addressed in our study design, we noticed greater artifacts from ferromagnetic susceptibility with GRASE imaging than with turbo spin-echo imaging (Fig 5). This may pose a limitation to the utility of GRASE in patients with internal metallic hardware.

As in echo-planar imaging, chemical-shift artifacts in GRASE sequences are more prominent along the phase axis of the image than along the frequency axis, because of frequency sensitivity through the echo train (4). However, in GRASE imaging, chemical-shift effects and field inhomogeneity evolve over the relatively short time period between 180° pulses, whereas in echo-planar imaging they have a longer time to develop (the time of the total echo train). Hence, GRASE sequences have relatively fewer of these artifacts than do echo-planar imaging sequences (4). Although there was significantly more chemical-shift artifacts in the phase-encoding direction with GRASE imaging than with turbo spin-echo imaging, we do not think this was detrimental to image quality or interpretation (Fig 4). Also, these artifacts could be reduced by using frequency-selective fat saturation (4, 10–12).

In our study, the GRASE technique maintained the contrast resolution of turbo spin-echo imaging and afforded improved detection of high-signal lesions ($P < .05$). The reason the GRASE technique maintained the contrast resolution provided by turbo spin-echo imaging is that the multiple spin-echo component was used to fill the center of k-space. The actual improvement in detection of high-signal lesions on GRASE sequences as compared with turbo spin-echo sequences is probably not intrinsic to the GRASE technique itself but is related to the longer repetition time used with the GRASE sequence (5503 milliseconds) relative to the turbo spin-echo sequence (3164 milliseconds).

One other observed difference between the two techniques, which was not addressed in our study design, was related to fat signal. One well-recognized effect with T2-weighted turbo spin-echo imaging is that fat tends to have a high signal (13, 14). On GRASE images, fat was persistently lower in signal intensity than it was on the turbo spin-echo images (Fig 2). Although this observation probably does not have a significant impact on brain imaging, it may prove useful for T2-weighted imaging of the neck and spine. Also, we noted decreased signal intensity from fat in the bone marrow on GRASE images relative to turbo spin-echo images. This may improve the ability to detect bone lesions (ie, metastases) on fast T2-weighted sequences.

In conclusion, T2-weighted GRASE is a fast imaging technique with a potential for replacing turbo spin-echo in routine MR imaging of the brain. GRASE maintains the contrast resolution of turbo spin-echo, is faster, and is better at depicting lesions with paramagnetic susceptibility characteristics, such as calcium and hemorrhage.

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