Editorial

Gradient Echoes: Simplified

Over the last 2 years the number of articles describing new uses of gradient echoes (GEs) has increased steadily. At first, GE imaging was heralded because of decreased imaging time compared with spin-echo (SE) imaging [1]. Its ability to create a myelographic effect in the spine, and its improved sensitivity in identifying blood products made GE imaging a valuable addition to supplement SE pulse sequences. More recent articles have documented the importance of GE imaging in evaluating flow in aneurysms and in identifying metastasis to the spine. During this same time, confusion developed because acronyms have been coined highlighting special characteristics of GE imaging. These include FLASH (fast low-angle shot, Siemens), FISP (fast imaging with steady precession, Siemens), GRASS (gradient-recalled acquisition in the steady state, General Electric), and FAST (fast acquisition steady-state, Picker). All of these are simple variants of GEs. The confusion from acronyms may well explain the delayed clinical application of GE imaging as a supplemental pulse sequence.

We would like to offer a simplified approach to GE imaging by looking at the intrinsic MR properties of tissue and at how the uniqueness of GE imaging can probe these to furnish added information.

The intrinsic MR properties of tissue include T1 and T2 relaxation times, proton density (N), magnetic susceptibility (X), chemical shift (δ), and flow. The importance of examining the appropriate inherent properties can be highlighted by a historical note. During the early clinical investigation of MR, the T1-weighted images acquired through inversion recovery yielded beautiful anatomic images with high spatial resolution. However, T1 weighting failed to identify pathologic lesions reliably, a deficiency that was corrected with the introduction of SE sequences, including intermediate- (proton-density) and T2-weighted sequences.

The different configurations of the SE and GE pulse sequences allow the inherent properties of tissues to be examined differently, thereby influencing the information gathered. Both pulse sequences sample the signal from echoes. GE sequences replace the 180° refocusing RF pulse in SE sequences with a reversal of the read gradient to rephase transverse magnetization. The lack of a 180° pulse allows greater signal loss in T2 weighting from inhomogeneities in the applied magnetic field (e.g., inadequate shimming), and induced, internal, local magnetic fields (e.g., old hemorrhage) because gradient recall cannot rephase these inhomogeneities. The signal loss in GE T2 weighting is called T2* ("T2-star") and is a combination of magnetic field inhomogeneities and spin-spin transverse relaxation (T2). The lack of the 180° pulse decreases energy deposition, allowing an increase in the number of excitations, thereby improving the signal-to-noise ratio compared with the ratio for SE sequences. GE sequences use a variable flip angle to create transverse magnetization, whereas SE sequences use the conventional 90° pulse. With GE imaging, image contrast is related to the flip angle and the TEs. Shorter TRs can be used in both T1 and T2 weighting while maintaining or improving image contrast. The shorter TRs allow rapid imaging with GE sequences.

The exact TR, TE, and flip angle will vary, depending on results desired and on the strength of the magnetic field of the unit. GE T1-weighted images are obtained by using a large flip angle (60–90°), a short TR, and a short TE (10–20 msec). GE imaging can use extremely short TRs (20–100 msec) vs those for SE imaging (400–600 msec). SE imaging requires a longer TR than GE imaging does to allow regrowth of longitudinal magnetization to create tissue contrast. GE imaging can maintain, or improve, contrast on T1-weighted images by using shorter TEs and increasing the repetitions. T1 contrast can be further augmented by using a gradient spoiler pulse after the echo to eliminate any residual transverse magnetization (the FLASH technique). Several investigators have replaced their SE T1 weighting with FLASH because of this improved T1 contrast.

Because of the rapid acquisition of single-slice GE T1-weighted images, flowing blood can be made bright by using the "entry slice phenomenon" [2]. Blood flowing into the

imaging slice has not received a pulse and is fully magnetized. The stationary tissue within the slice is partially saturated by the repeated pulses—not having recovered full magnetization. Therefore, the strong signal elicited from unsaturated blood reflects full magnetization. The entry slice phenomenon has been used to create a bright signal in arteriovenous malformations with rapid flow, whereas thrombosed malformations would have a null signal. Because of the rapid acquisition of GE T1-weighted images, aneurysms can be examined in all three orthogonal planes as additional pulse sequences without disrupting scheduling of patients [3].

GE T2-weighted images are obtained by using a small flip angle (6–20°), a short TR (50–500 msec), and a long TE (30–100 msec). GE T2-weighted images are not hampered by a long TR to eliminate T1 effect as SE images are. Therefore, GE T2-weighted images can be obtained quickly by using a small flip angle, a large TE, and a short TR. T2 effect is accentuated by decreasing the flip angle and/or prolonging the TE. The advantages of GE T2-weighted images over SE T2-weighted images are their short acquisition time and their ability to maintain signal in fluids or substances with long T2* (e.g., CSF and disk) [4]. A weakness is the greater signal loss from T2*, which can overshadow signal loss from spin-spin relaxation (T2 relaxation), thereby hiding lesions [5].

Knowing the strengths and weaknesses of GE T2-weighted images, the radiologist can choose if tissues with long T2* should be accentuated (e.g., to create a myelographic effect for CSF) or if a rapid T2-weighted survey should be obtained (e.g., in a claustrophobic patient who refuses sedation).

Another strength of GE imaging is the evaluation of magnetic susceptibility. Magnetic susceptibility is the ability of a substance to become magnetized when placed in an applied magnetic field. A substance can be diamagnetic, paramagnetic, or ferromagnetic, depending on whether the induced local field opposes, weakly augments, or strongly increases the applied field. GE imaging is extremely sensitive to the presence of small amounts of paramagnetic and ferromagnetic substances because of the induced local magnetic fields. These local magnetic fields cause visible signal loss on GE T2-weighted images because of T2*. This signal loss can be emphasized in GE imaging by decreasing the flip angle and/or prolonging the TE. The value of investigating magnetic susceptibility is identification of diamagnetic substances (calcifications) [6] and paramagnetic substances (physiologic and pathologic areas of iron deposition) [7].

Unfortunately, large differences in local magnetic fields at interfaces cannot support the same magnetic flux density, thereby creating a signal loss at interfaces. The signal loss is most noticeable at the sinus-brain and CSF-osteophyte interfaces [8]. The magnetic susceptibility effect at interfaces can be lessened by shortening the TEs; the T2* effect can be maintained by the small flip angle [4]. For studying the spine, the GRASS technique uses the short TE to eliminate the signal loss at the CSF-osteophyte interface; the small flip angle maintains the myelographic effect [4].

GE imaging allows rapid evaluations of chemical shifts by choosing the appropriate TE. Water protons precess at a faster rate than fat protons (3.5 ppm). After being perturbed by an RF pulse and placed on the transverse plane, the protons of water and fat dephase. There is a cyclic increased and decreased signal, depending on whether the water and fat protons are in or out of phase. If the water and fat protons are in phase, their signal is additive. If they are 180° out of phase, their signal is canceled. The choice of the TE determines whether protons have cycled to a position in or out of phase [9]. At a field strength of 0.6 T, the water and fat protons are out of phase at 18, 29, 40, and 51 msec. Chemical shift becomes important in evaluating the spine for metastasis or a subtle fracture. Nulling the normal signal from the marrow increases the conspicuity of water-dominant tumors and trauma.

In conclusion, GE imaging should be used as a supplemental pulse sequence to investigate lesions seen on SE pulse sequences. The rapid acquisition possible with GE sequences and choosing only the appropriate sequence to study an intrinsic tissue property should not disrupt scheduling of patients. GE T2 weighting should not be the primary imaging sequence because these images are hampered by magnetic susceptibility at interfaces, and lesions having subtle spin-spin relaxation changes may be obscured by T2* effects. Also GE imaging is more susceptible to the artifacts produced by paramagnetic materials, such as those found in CSF shunt valves.

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