Spoiled Gradient Echo (SPGR) Ghost Artifact in Endoluminal MRI

A. C. Yung1,2, E. Atalar3
1Johns Hopkins University, Baltimore, MD, United States

Synopsis
Ghost replicas of endoluminal MR coil outlines have been observed in spoiled gradient echo (SPGR) sequences. The artifact is not caused by motion, and originates from oscillations in the incompletely RF-spoiled transverse magnetization that remains after each excitation. Changing the value of the linear RF phase increment (i.e., the seed value) affects the positions of the ghosts, while the TR, flip angle, and relaxation times affect only their amplitude. Computer simulations correctly predicted the locations of the ghosts observed in experiments, for a variety of seed values.

Introduction
In our experience with endoluminal MR imaging (1-3), we have encountered sequence-dependent ghost replicas of the internal coil outline along the phase encode direction, even when motion is not present. One form of sequence-dependent ghosting artifact arises for spoiled gradient echo (SPGR) imaging. In SPGR, RF spoiling (i.e., elimination) of residual transverse magnetization is achieved by attempting to randomize the initial phase of the transverse magnetization by linearly incrementing the RF phase shift after every excitation (4). We show that ghost artifacts originate from oscillations in the incompletely RF-spoiled transverse magnetization.

Methods
Axial images of a polycrylamide cylindrical phantom were acquired on a GE Signa 1.5T scanner with an array of two rectangular coils mounted on a silicone probe (described in (5)). The RF spoiling algorithm (4) increments the phase shift, θ, of excitation i with the seed value (θi = θi-1 + i*seed). Dependence of the ghosting behavior on TR, flip angle and seed value was studied for GRE and SPGR sequences. The default seed value on the GE scanner was tested (115° for fast SPGR), as well as the seed value of 45°. The time evolution of spins within a voxel was simulated using the Bloch equation with relaxation terms considered (T1 = 1600 ms, T2 = 200 ms, 100 spins uniformly distributed between 0 and 2π), and then convolved with a delta object function located at the experimental signal peak position. Gradient warping and Fermi filtering were turned off during the experiments.

Results
Figure 1 shows ghost replicas of the internal coils along the phase encode direction in GRE and SPGR images, for different TRs (TE=4.4 ms, FOV=21 cm, slice thickness=3 mm, 256x256, 1 NEX, α = 12°, SPGR seed = 115°). The ghosts that are common to both sequences (“GRE ghosts”) change position when TR is varied, whereas the position of the SPGR-specific ghosts are independent of TR. This result verifies that the RF spoiling mechanism is the cause of the SPGR-specific ghosts (GRE is identical to SPGR, except that it lacks the spoiling mechanism). Figure 1 further shows that SPGR ghost intensity increases when TR is decreased, but the positions remain the same. Changing the flip angle also affected the ghost amplitudes but had no effect on their positions. The top row of Figure 2 (experimental signal profiles along a column of pixels) show that the ghost positions change with seed value (SPGR; TE/TR=4.4/34 ms; FOV=21 cm; slice thickness=3 mm; 256 x 256; 1 NEX. Experimental α = 12°; simulation α = 90°). The ghost positions predicted by simulation (bottom row of Figure 2) exactly match the observed ghost positions.

Discussion
Experimental data confirms that ghosting in SPGR arises from oscillations in the incompletely spoiled transverse magnetization. The periodicity of these oscillations produces a modulation function that, when convolved with the underlying signal, produces replicas of the object. The exact frequencies of the oscillation (and therefore the positions of the ghosts) are dependent on the seed. If the seed value is a small rational fraction of a cycle (e.g. Figure 5a: 45° = 1/8 cycle), the period of oscillation is small, because less repetitions are needed before the RF phase shift returns to its original value. A seed value such as 115° (Figure 5b) require more repetitions for the RF phase shift pattern to repeat, leading to fewer and more widely spaced ghosts.

Other parameters affect only the amplitude of the ghosts by varying the amount of residual transverse magnetization available for oscillation: a short T1 and large flip angle increases the amount of longitudinal magnetization that is converted into transverse magnetization, whereas a long TR and a short T2 produces a larger decay in the transverse magnetization before the next RF pulse.

The flip angle used in the simulations (90°) was set higher than the experimental flip angle (12°), in order to elucidate the positions of the ghosts as predicted by theory (the results are valid because the ghost locations are independent of flip angle). The fact that the simulated ghost amplitudes were much lower than the observed amplitudes can be explained by several reasons. For example, the region adjacent to the coil may have had different T1 and T2 than the rest of the phantom (e.g. as a result of fluid accumulation). Imperfect coil decoupling during transmit may have resulted in currents that amplified the flip angle near the coil, resulting in an increase in the ghost amplitudes; this effect would be significant even if the flip angle amplification occurred for only a portion of the spins within the voxels next to the coil. One possible method of removing the artifact is to order the phase encoding acquisitions so that the periodicity of the spurious oscillations across lines of k-space is disrupted.

Conclusion
SPGR ghosting artifacts not caused by motion were observed for internal coils. Experimental data and computer simulations indicate that the source of the ghosting artifacts is the oscillation of incompletely spoiled transverse magnetization. The value of the linear RF phase increment affects the ghost positions, while the TR, flip angle, and relaxation times affect the amplitude of the ghosts.

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References