Phase refocusing for improved visualization of interventional guidewires

W. Overall[1], G. Scott[1], Y. Suzuki[2], M. Terashima[2], F. Ikeno[2], M. McConnell[2], and J. Pauly[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Cardiovascular Medicine, Stanford University, Stanford, CA, United States

Introduction: Robust visualization of interventional guidewires is difficult because typical guidewire diameters of 0.035" and 0.018" are too small to accommodate tracking microcoils. Active guidewire receivers [1,2] have been used to accomplish this task, but the received signal profile is not strongly peaked around the wire, confounding efforts at automated tracking or guidewire-signal overlay. This signal behaviour occurs because dispersion in receiver phase causes signal cancellation near the wire. Here, we explore the use of a rephasing gradient to counteract this phase dispersion while suppressing signal far from the guidewire. Previously, 'projection dephasers' have been used to highlight gadolinium-filled catheters [3]; this technique uses a similar mechanism for background suppression, but also exploits spin rephasing for signal enhancement near the guidewire.

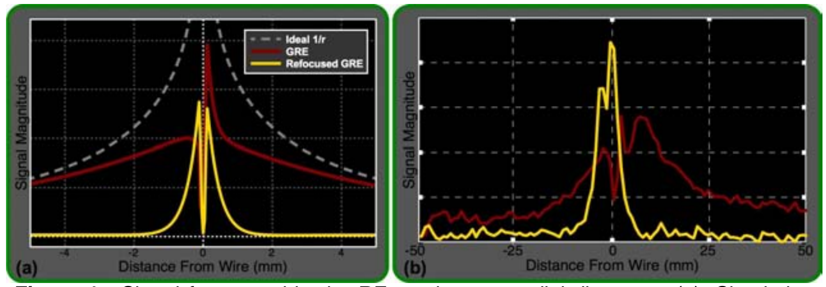

Figure 1. Signal from a guidewire RF receiver vs. radial distance. (a): Simulation; (b): Experiment. Standard GRE signal (red) is lower and less sharply peaked than the ideal 1/r (gray) due to phase cancellation. The insertion of a rephasing gradient restores the sharp near-wire peak and suppresses background signal (yellow).

Methods: The magnitude sensitivity of a guidewire RF receiver is ideally proportional to $1/r$, where r is the radial distance from the wire (Fig. 1(a)). However, the guidewire receiver's phase varies radially, with the received phase equal to the angular position about the wire. As a result, phase cancellation occurs over the finite extent of the voxel, and image signal is lower than the optimal $1/r$. Spin dispersion increases with proximity to the wire, and as a result, signal is not strongly peaked at the wire. To counteract this effect, we add a 'rephasing gradient' prior to readout in a GRE pulse sequence, with area A_s equal to the spoiler area and on the same gradient axis (Fig. 2). This gradient dephases signal far from the wire while rephasing spins for signal enhancement at certain locations near the wire. The rephasing gradient area is made equal to the spoiler area so that the GRE 'fid' and 'echo' signals are each weighted equally, resulting in nearly symmetric signal from either side of the wire. Increasing rephaser and spoiler areas together results in both improved background suppression and increased sharpness of the near-wire signal.

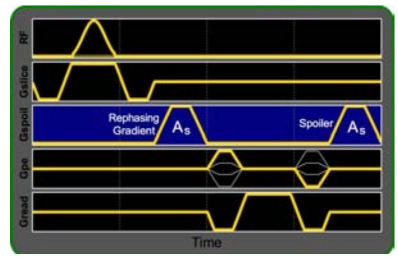

Figure 2. Rephased GRE sequence. A rephasing gradient is added on the spoiler axis prior to readout.

We implemented this sequence with TR=4.0 ms, TE=1.6 ms, 256^2 matrix, 24-cm FOV, and a 1-cm slice, for an in-plane resolution of 0.94 mm. A 0.018" nitinol wire (Terumo GlideWire©) was resistively coupled to a 1.5T research scanner for use as an active receiver [1]. Total imaging time was 1.5 sec, or around 1 frame per second for dynamic scans. Phantom studies were conducted to validate the technique and compare acquired signal profiles with theory. To validate the technique's applicability for vascular interventions, we applied the sequence in an ex-vivo porcine carotid artery that contained thrombus generated by 24-hr occlusion.

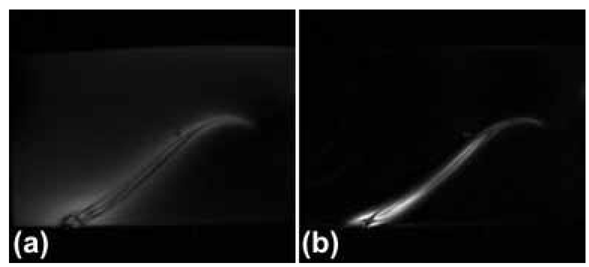

Figure 3. (a): GRE image acquired using the guidewire as an RF receiver. (b): When a rephasing gradient is applied, background signal is nulled and signal increases near the wire. Brightness and contrast are the same for (a) and (b).

Results: Fig. 1(b) shows a plot of signal from a single image line perpendicular to the wire receiver for sequences with and without the refocusing gradient. Acquired signal qualitatively matches theory, with a measured signal-to-background ratio (SBR) of 4.2 in the GRE case compared to 18.9 for refocused GRE. The centroid of coil signal is more precisely centered on the wire for refocused GRE, and signal rephasing is evident because peak signal at the wire nearly doubles when refocusing is used. This enhancement is better than predicted, and may be the result of transmit coupling from the body coil.

Phantom images acquired with and without rephasing (Fig. 3) also demonstrate this signal enhancement along with sharper delineation of the wire location. Though signal intensity drops toward the end of the wire, the tip location is still easily seen. Images acquired with body-coil transmit and receive have no coil-phase weighting and show little or no wire signal, further demonstrating that signal enhancement arises from phase unwrapping. Images acquired in the ex-vivo artery (Fig. 4) also exhibit sharp signal well localized to the wire. For overlaying guidewire signal over anatomic images, we tested both rapid GRE anatomic imaging and pre-acquired T2-weighted FSE roadmaps. The superior contrast of the FSE anatomy was preferred for this ex-vivo study, despite the lack of real-time anatomic updating. The wire position and orientation were easily visualized with a thresholded guidewire overlay.

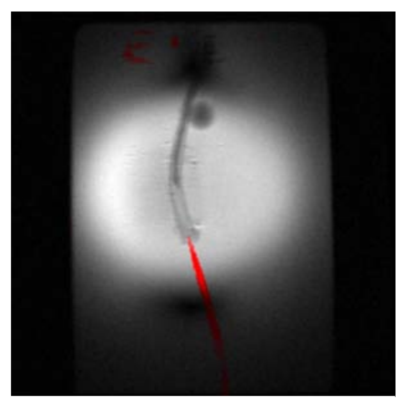

Figure 4. Rephased guidewire signal (red) overlaid on a FSE image showing initial entry into an occluded porcine carotid artery. The precise position and orientation of the tip is well visualized.

Discussion: We have demonstrated a promising GRE sequence for high-fidelity guidewire visualization during interventions. The sequence is compatible with most rapid imaging protocols routinely used, and may be interleaved with anatomic imaging for real-time wire overlay. For SSFP contrast, a similar approach may be employed with inverted rephasing area, $-A_s$. The concept of rephasing may also be applicable to rf microcoil receivers for active tracking applications; such a technique could improve the accuracy and precision of position measurements.

References: [1]. Scott GC, *et al.* Proc. 14th ISMRM: 266, 2006. [2]. Ocali O, *et al.* MRM 37(1): 112-118, 1997. [3]. Omary RA, *et al.* JVIR 11(8): 1079-1085, 2000.