SLEDGE (Spin-Locked Evolution During Gradient Echo) Pulse Sequence for Imaging Short T_2* Species

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Introduction

The imaging of short T_2* species presents a challenging endeavor for the MR community. Tissues with short T_2* appear dark in gradient-echo images due to the presence of a significant susceptibility artifact at the air-tissue interface. Several reports have been published concerning the imaging of such species using gradient-echo sequences with ultra-short TE times [1], projection reconstruction [2], or turbo spin-echo methods [3]. We propose the use of a "spin-lock" rf pulse to reduce susceptibility-induced signal loss. The hypothesis is that the application of a low-power on-resonance spin-lock pulse during spin dephasing and rephasing will preserve the coherent magnetization by "locking" transverse spins thereby mitigating irreversible spin dephasing caused by susceptibility. In this work, we develop the novel pulse sequence SLEDGE (**S**pin-**L**ocked **E**volution **D**uring **G**radient **E**cho) to increase signal in gradient-echo images using a spin-lock pulse during gradient dephasing and rephasing.

SLEDGE Pulse Sequence

In the SLEDGE sequence (Figure 1), a low-power, long-duration, self-compensating spin-lock pulse is applied during the gradient dephasing lobe and first half of the rephasing lobe. The phase of the second half of the self-compensating spin-lock pulse is 180° out of phase with the first half to reduce artifacts caused by B_1 inhomogeneity. A partial echo is acquired only during the second half of the rephasing lobe in order to avoid interference in the rf coil from the application of the spin-lock pulse.

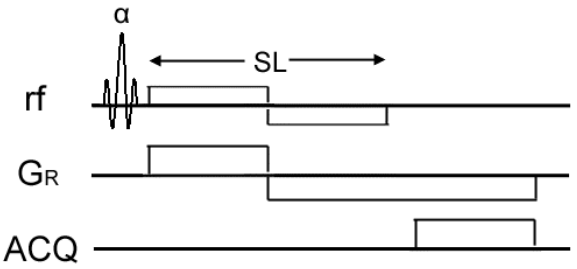

Figure 1 SLEDGE pulse sequence diagram. For simplicity, only the rf, gradient read (G_R), and acquisition (ACQ) channels are shown. Following the α excitation pulse, a self-compensating spin-lock pulse (SL) is applied during the gradient dephase and rephase lobes. A partial echo is acquired in the second half of the rephasing gradient lobe.

Methods

All MR images were acquired on a Varian 4.7T INOVA research console using a 2 cm diameter linear birdcage rf coil. The sequence was tested on a cylindrical phantom made of agarose gel (4% weight/vol) with T_1 and T_2* measured to be 880 ms and 18 ms, respectively. The SLEDGE sequence was applied to acquire a single slice using parameters of TE = 10 ms, TR = 300 ms, slice thickness = 3 mm, 2 averages, FOV = 40 mm x 40 mm and an acquisition matrix of 512 x 256. The sequence was repeated for six spin-lock amplitudes (γB_1 = 80, 160, 225, 300, 450, and 640 Hz). For comparison, an image was acquired using a conventional gradient-echo sequence with identical parameters as the SLEDGE acquisition.

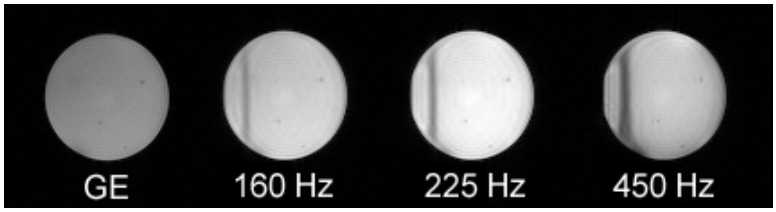

Figure 2 Comparison of a conventional gradient echo image (GE) and representative SLEDGE images. The average signal intensity of the 160, 225, and 450 Hz SLEDGE images was 49%, 68%, and 33% greater than the GE image.

Results & Discussion

The average signal intensity of the SLEDGE images was greater than that of the conventional gradient echo image (Figure 2). The dark vertical line in the SLEDGE images is the result of the well-characterized "hole-burning" artifact caused by the on-resonance rf pulse during the presence of gradients [4]. The severity of this artifact increased with spin-lock pulse amplitude as expected. The hole-burning artifact is localized to the zero-position of the frequency encode gradient direction and can be managed by placing the object of interest away from the gradient center. The signal intensity of the SLEDGE images was a function of the amplitude of the spin-lock pulse (Figure 3). The signal intensity decreased with increasing spin-lock amplitude past 225 Hz as the signal losses from the saturation of longitudinal magnetization by the on-resonance spin-lock pulse increased. In practice, the spin-lock pulse amplitude must be optimized for individual experimental conditions to balance the signal increase from the SLEDGE effect with the signal loss from saturation of longitudinal magnetization.

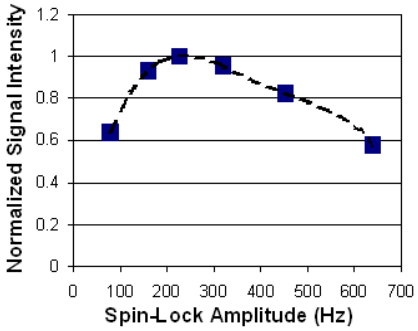

Figure 3 Average signal intensity of SLEDGE images as a function of spin-lock amplitude.

Conclusion

The SLEDGE sequence increased signal intensity up to ~70% in phantom experiments by reducing signal loss due to susceptibility-induced spin dephasing. This substantial signal increase can be used to improve the SNR of MRI of short T_2* tissues with significant susceptibility artifacts such as lung parenchyma. This work is a first step in the development of the SLEDGE sequence for in vitro and in vivo use.

References

1. DC Alsop, et al. *Magn Reson Med* 1995;(33):678-92.
2. CJ Bergin, et al. *Radiology* 1991;(179):777-81.
3. H Hatabu, et al. *Eu J of Radiology* 1999;(29):152-9.
4. EE Sigmund and WP Halperin. . *JMR* 2003;(163):99-104.