The Effect of RF Phase-Cycling on the T1 Contrast of the Brain

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Introduction

The phase cycling of the excitation pulse in a spin echo sequence can have a subtle influence in T1 contrast. This occurs, as we explain, due to the presence of a low-level stimulated echo (STE) signal. Optimal T1 contrast is achieved when the excitation pulse phase is alternated between 0° and 180° on consecutive measurements. This effect creates perceivable White-Gray Matter contrast difference in brain imaging. The level of contrast enhancement depends on the T1 values of the tissue. Tissues with longer T1 are more susceptible to the presence of STEs during the data acquisition.

Theory

A large number of multiple order echoes are potentially generated by any series of RF pulses (1). However most are either eliminated by crushing gradients or considerably reduced during the relaxation periods.

Consider generalized excitation and refocusing pulses in a spin-echo sequence (as shown in Fig. 1) and denote their respective flip angles by α_1 and α_2. There are two main simultaneous echoes requiring consideration; these are the main spin echo (SE) from each excitation-refocusing pulse pair, and a parasitic stimulated echo (STE) from pairs of the spin echo producing pulse pairs.

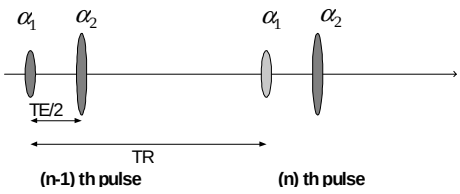


Figure 1

Assuming that the echo time is much less than the repetition time (TR), the steady state longitudinal magnetization of tissue, with a relaxation time T1, is given by $M_z = (1-\exp(-TR/T1))/(1-\cos(\alpha_1)\cos(\alpha_2)\exp(-TR/T1))$; and the amplitude of the SE is $A_{SE} = \rho M_z \sin(\alpha_1)\sin^2(\alpha_2/2)$, where ρ is the proton density (2).

The STE at the (n)th acquisition is originated by (n-1)th excitation-refocusing pulse pair. It is attenuated by the excitation pulse at the (n)th acquisition, and finally converted back to transverse magnetization by the refocusing pulse in the (n)th acquisition. The amplitude of the STE can be calculated as $A_{STE} = \rho M_z \sin(\alpha_1)\sin^2(\alpha_2)\cos(\alpha_1)\exp(-TR/T1)/2$.

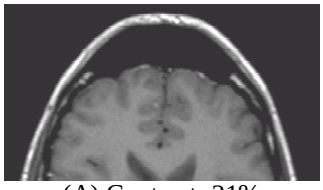
For ideal excitation and refocusing pulses the STE has zero amplitude. However with slice selective imaging there are necessarily regions within the slice profile where the excitation and refocusing pulses deviate from their ideal 90° and 180° values, respectively. Hence a small STE is always present.

Note that the STE has a T1 contrast different from that of the SE. Hence if the smaller STE is acquired positively with respect to the larger SE, the overall contrast is reduced, and vice versa. The sign of the STE with respect to the SE can be altered by appropriately phase cycling the excitation pulses. By applying an excitation phase sequence of [0°, 0°, 0°, 0°,...] the STE and SE are acquired with the same sign. A sequence of [0°, 180°, 0°, 180°,...], on the other hand causes the STE and SE to have opposite sign.

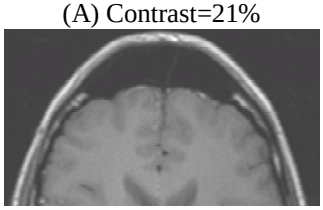
Applying a phase sequence such as that used in phase-spoiled gradient recalled echo sequences coherently dephases the STE, and hence eliminates it altogether.

Methods

The excitation phase cycling was modified on a standard multi-slice clinical spin echo sequence, brain images were acquired, and the gray matter (GM) to white matter (WM) contrast was evaluated for the various above mentioned phase cycles. All phantom and volunteer scans were run on a GE 1.5T Signa System with 9.0 Software. Simulation studies were done using MATLAB™. The sequence parameters were TR/TE=500/20ms, 4mm slice, 2NEX, 256x192, 15-slices 16KHz BW. Contrast was calculated as the percentage, 100*(WM-GM)/WM.



(A) Contrast=21%



(B) Contrast =15%

Figure 2

Results

The top and bottom images in Fig. 2 shows typical results with the [0°, 180°, 0°, 180°,...] and [0°, 0°, 0°, 0°,...] excitation phase sequences, respectively. The alternating phase sequence has 40% more contrast than the constant phase sequence.

Conclusion

For improved contrast, T1 weighted spin echo imaging should be performed with an alternating excitation phase sequence. This effect is particularly important in WM-GM Contrast in the brain. Tissues with longer T1 are more susceptible to the presence of STEs during the data acquisition.

References:

1. Zur Yet al. J Magn Reson 1987; 71:212-228.
2. Woessner DE. J Chem Physics 1961; 34(6): 2057-2061.