Dependence of gradient echo phase contrast on the differential signal decay in subcellular compartments

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TARGET AUDIENCE: Anyone interested in using gradient echo signal phase and magnetic susceptibility contrasts to characterize brain tissue.

PURPOSE: Phase images acquired by gradient-recalled-echo (GRE) sequences have provided a new contrast for MRI and a wealth of information of biological tissues. It is well known that the magnitude contrast of GRE signal varies significantly as a function of sequence parameters such as TR, TE and flip angle. Surprisingly, the dependence of phase contrast on these parameters has not been explored. In fact, phase contrast has largely been assumed to be insensitive to sequence parameter in the literature. However, biological tissues, especially brain tissues, have complex microstructures that contain multiple compartments of varying properties. The relative contributions of these compartments to GRE signal certainly depend on the aforementioned sequence parameters. In this study, we have comprehensively evaluated the dependence of phase contrasts on TE, TR and flip angle. Our results showed that the phase contrast has a profound dependence on image acquisition parameters as a result of differential T1 and T2 (or T2*) signal decay of different compartments with different magnetic properties.

METHODS: *Brain Imaging*: One healthy adult was scanned using a GE MR750 3T scanner equipped with an 8-channel head coil, using a multi-echo GRE sequence. The first dataset was acquired with multiple flip angles and with the following parameters: flip angle = 5º, 20º, 40º and 60º; TE1=4 ms, echo spacing = 2.12 ms, TR = 50 ms, voxel size = 1x1x2 mm^3. The second dataset has multiple TRs and the parameters were: flip angle = 30º; TE1=4 ms, echo spacing = 2.12 ms, TR = 46 ms, 150 ms and 1s, voxel size = 1x1x4 mm^3.

Data Analysis: The image phase from different coils were unwrapped using an Laplacian-based method and combined, and the background phase were removed using a modified SHARP method as previously described (1,2). Regions of interest (ROI) were selected in splenium of the corpus callosum and adjacent gray matter using an in-house developed software (Fig. 1). The complex MR signal of the selected white matter (red ROI) can be described using the following two-compartment model:

$$S(TE) = \sum_i \rho_i \exp\left(j \cdot 2\pi f_i TE - \frac{TE}{T_{2i}} \right) \cdot \sin\theta \cdot \frac{1-\exp(-TR/T_{1i})}{1-\exp(-TR/T_{1i})\cos\theta} \qquad [1]$$

where S is total NMR signal, ρ is the relative pool size of the compartment, f is the frequency shift of the gray matter relative to the adjacent gray matter (green ROI), and θ is the flip angle. As a preliminary investigation, we fixed the pool sizes to values reported in the literature. The goal was to determine the magnetic properties of each compartment. The parameters were fitted using a non-linear least square curve fitting. The size of compartment 1 is assumed to be 14% to reduce the number of variables.

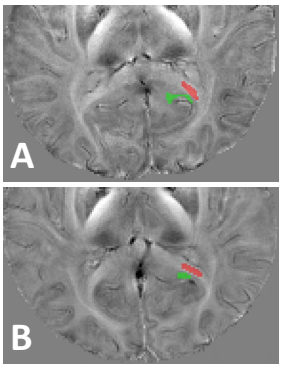

Fig. 1. Regions of interest. A: multiple flip angle dataset; B: multiple TR dataset. Red: white matter. Green: gray matter.

RESULTS: Similar to the magnitude, GE signal phase is also strongly dependent on flip angle and TR. In addition to the nonlinear evolution of the gray and white matter contrast with TE, importantly, frequency shift decreases as the flip angle is reduced or the TR is increased. This property is especially prominent at short TEs. Such dependence can be well described by the above two compartment model (Eq. 1), as demonstrated by the good agreement between the model fitting and the experimental data. The fitted model parameters were summarized in Table 1.

DISCUSSION AND CONCLUSION: Our *in vivo* data showed that GE signal phase have a profound dependence on the image acquisition parameters, including TE, TR and flip angle. Such dependence was due to the district frequency shift of the different water compartments within white matter. One implication of the results is that care needs to be taken when comparing susceptibility and phase values between different subjects and different studies. Maintaining consistent sequence parameters are critical for inter-subject reproducibility. Further, our results could suggest that the frequency and susceptibility contrasts could be significantly altered by changing the scan parameters, which could potentially provide a convenient means to selectively image different compartments of the tissues. By simply changing sequence parameters, it may also allow us to probe the microstructures of tissue with better details. Future studies will need to determine the number of compartments that are necessary to fully explain the data using more sophisticated optimization techniques.

REFERENCES: (1) Schweser et al, NeuroImage, 2011; 54:2789. (2) Li et al, Neuroimage 2001; 55:1645.

Table 1. Fitted parameters for the proposed model (Eq. 1)

	Compartment 1 (14%)		Compartment 2 (86%)	
	Multi-FA	Multi-TR	Multi-FA	Multi-TR
***f* (Hz)**	-16.2	-7.3	2.3	2.6
T1 (ms)	67	90	263	900
T2 (ms)	10	15	57	80

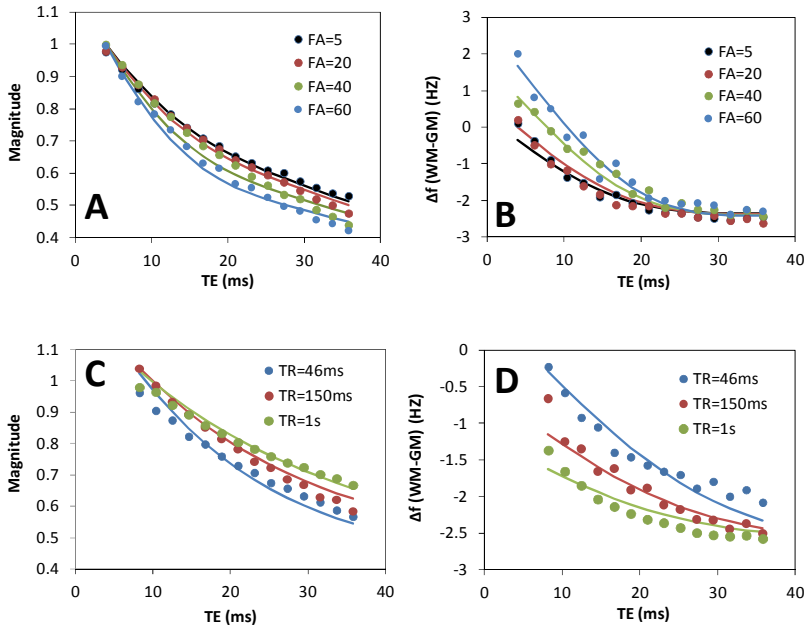

Fig. 2. Dependence of Magnitude and frequency shift of the white matter on TE, flip angle and TR. WM: white matter, GM: gray matter.