Accelerated Gradient-Recalled Echo, Asymmetric Spin-Echo (GREASE-II) for Production of High-Resolution Human T1, T2, and T2* Maps

D. L. Shefchik1, A. S. Nencka1, A. Jesmanowicz2, and J. S. Hyde1
1Department of Biophysics, Medical College of Wisconsin, Milwaukee, WI, United States

Introduction: The gradient-recalled echo, asymmetric spin-echo (GREASE) pulse sequence was developed to study the $T_2$ dependence of the functional blood oxygenation level dependent (BOLD) signal (1). This pulse sequence includes three, full echo-planar imaging (EPI) readouts following a single excitation, with the final two readouts positioned equally around a spin echo. Additionally, previous work from this lab found $T_1$ through varying TR throughout the acquisition (2). A new version, called GREASE-II, was developed to include acquisition acceleration, additional readouts and multiple TRs to acquire $T_1, T_2, T_2^*$, on a voxel-wise basis.

Theory: The GREASE-II pulse sequence, described in Figure 1, can include a very long readout time. In order to maintain signal intensity in later echoes, GREASE-II utilizes a combination of generalized autocalibrating partially parallel acquisition (GRAPPA) and partial Fourier acquisition (3,4). This acceleration allows increased signal-to-noise ratio, reduced point-spread function in the phase-encoding direction, increased slice coverage for a given repetition time and enhanced availability of additional EPI readouts following an excitation.

The reconstructed signal equation for each echo is:

$$I(x, y) = a(x, y)\rho(x, y)(1 - e^{-\frac{t - \gamma B_x y}{\gamma T_2}}) e^{-\frac{\gamma B_x y}{\gamma T_1}} e^{-\gamma B_x y t},$$

where $a(x, y)$ is a spatially varying unknown gain factor; $\rho(x, y)$ is the proton spin density; $t$ is the time after the excitation that the k-space image is sampled; $\gamma$ is the time difference between the sampling time and the time of the nearest spin echo, or excitation in the case of time before the first refocusing pulse; $\gamma$ is the gyromagnetic ratio of the element being imaged; and $\Delta B(x, y)$ is the magnetic field inhomogeneity of the object being imaged.

If the signal-to-noise ratio is large, the magnitude of the reconstructed signal can be utilized to compute relaxivity maps. If $\tau_1 = \tau_2 = E T_E 1$, the two images after the first refocusing pulse have matching $\tau_1$ weightings so that $\tau_2$ may be directly estimated from the images as:

$$\tau_2 = (2 - \tau_1)/\tau_1 \ln \left( \frac{M_e(x, y)}{M_i(x, y)} \right).$$

Likewise, if echo 4 has an effective echo time of $\tau_4 = 0$ and echo 5 has an effective echo time of $\tau_5 = E T_E 2$, the decay rate of $\tau_5$ can be calculated as:

$$\tau_5 = E T_E 2 / \ln \left( \frac{M_e(x, y)}{M_i(x, y)} \right) \quad \text{where} \quad \frac{1}{\tau_2} = \frac{1}{\tau_1} = \frac{1}{\tau_3} = \frac{1}{\tau_4} = \frac{1}{\tau_5}.$$