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

D. L. Shefchik[1], A. S. Nencka[1], A. Jesmanowicz[1], and J. S. Hyde[1]
[1]Department 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_2, T_2*, T_1 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:

$$I(x,y) = a(x,y)\rho(x,y)(1-e^{\frac{-TR}{T_1(x,y)}})e^{\frac{-t}{T_2(x,y)}}e^{\frac{-\tau}{T_2'(x,y)}}e^{i\gamma\Delta B(x,y)\tau},$$

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 point is imaged; τ 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; γ 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 Tau1=Tau2=ETE1, the two images after the first refocusing pulse have matching T_2' weightings so that T_2 may be directly estimated from the images as: $T_2 = (2\cdot ETE1)/\ln\left(\frac{M_2(x,y)}{M_3(x,y)}\right)$. Likewise, if echo 4 has an effective echo time of Tau3=0 and echo 5 has an effective echo time of Tau4=ETE2, the decay rate of T_2^* can be calculated as: $T_2^* = ETE2/\ln\left(\frac{M_4(x,y)}{M_5(x,y)}\right)$ (where $\frac{1}{T_2^*} = \frac{1}{T_2'} + \frac{1}{T_2}$). Finally, T_1 can be determined numerically if the time between the initial 90-degree pulse and the 90-degree pulse preceding the sixth echo is R, as the ratio of the sixth and first echoes may be shown to be: $\frac{M_6(x,y)}{M_1(x,y)} = -2e^{-\frac{R-2SE}{T_1}} + 2e^{-\frac{R-SE}{T_1}} - e^{-\frac{R}{T_1}} + 1$.

Although care is taken to reduce effects of stimulated echoes and imperfect radio frequency (RF) pulses, these relaxivity calculations only compare signals following identical RF preparations, thereby avoiding potential confounds from RF effects.

Methods: A healthy human subject was imaged after informed consent was obtained. An 8-channel head receiver was utilized on a 3.0 T General Electric Signa LX scanner. The scanning parameters were TR = 2 s, TE = 11 ms, Tau1 = 13 ms, Tau2 = 13 ms, Tau3 = 0 ms, Tau4 = 26 ms, TE2 = 91.576 ms, R = 500 ms, flip angle 90 degrees, acquisition matrix 96 x 96, field of view 19.2 cm, slice thickness 2 mm, and 150 repetitions. Acceleration was achieved using partial Fourier acquisition with 8 overscan lines and GRAPPA with an acceleration factor of 2 and 4 ACS lines. T_2*, T_2, and T_1 were calculated as described above.

Results: The GREASE-II sequence yields sufficient signal in each echo image, which are displayed in Figure 2. Even with the large range of signal-to-noise ratios across the echoes the data yielded reasonable estimations of relaxivity parameters, shown in Figure 3. The T_1 map shows clear definition between gray and white matter. The T_2 map also shows differences between tissues, while T_2^* maps are rather homogenous due to the spatially varying B field with T_2^* less than T_2, as expected. In the T_2 images, the cerebrospinalfluid is noticeable with its relatively long relaxation, and subcortical gray matter has a significantly shorter transverse decay rate than cortical gray matter. T_1 of the tissues are similar, making differentiation through T_1 alone challenging.

The GREASE-II pulse sequence allows researchers to produce relaxivity maps with the same readouts used in their functional studies. This has the great potential of tissue segmentation in the same spaces as data are collected, enabling more aggressive image masking to reduce both false positives and the issue of multiple statistical comparisons. With this ability, more accurate fMRI and fcMRI studies can be conducted with 1-to-1 registration of the functional data to the underlying anatomy without the need for non-linear image registration.

References: 1. Bandettini et al. *Proc. ISMRM*. 5:1639 (1997). 2. Mazaheri, et al. NIMG 32:603-615 (2006). Griswold et al. MRM 47:1202-1210 (2002). 3. Jesmanowicz et al. MRM 40:754-762 (1998).

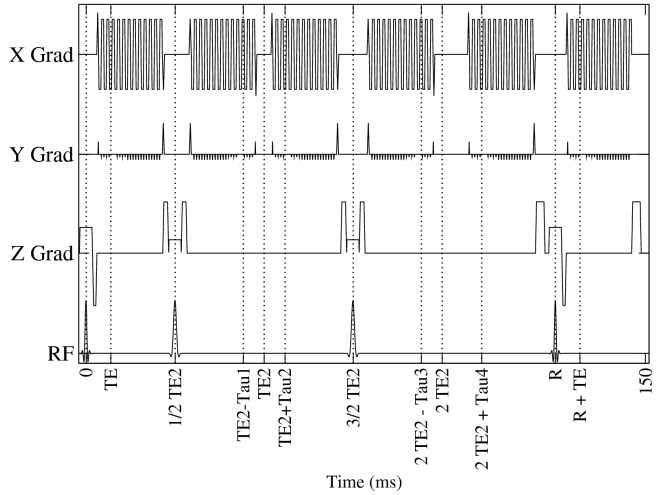

Figure 1: The GREASE-II pulse sequence includes six echo planar readouts. The first readout follows a 90-degree excitation pulse, at its minimal echo time of TE. The second and third readouts are placed symmetrically about a spin echo that occurs at TE2 with effective echo times of Tau1=Tau2=ETE1. The fourth and fifth readouts are placed asymmetrically about the second spin echo which occurs at 2*TE2, with effective echo times of Tau3=0 and Tau4=ETE2, respectively. A crusher gradient follows the fifth readout to dephase the transverse magnetization, followed by a 90-degree excitation pulse and an echo planar readout that is identical to the initial gradient recalled echo readout. To address the deleterious effects of fat on the EPI readouts, excitation pulses must be spatial spectral pulses, or be preceded by fat presaturation pulses.

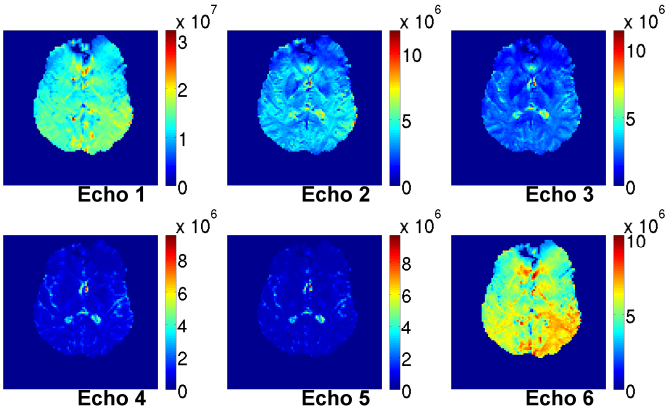

Figure 2: Six GREASE-II echoes.

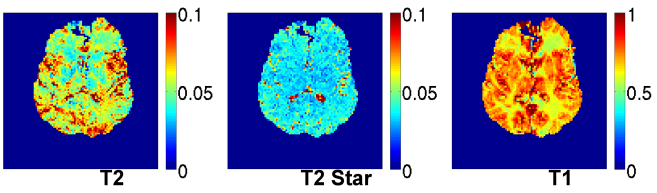

Figure 3. GREASE-II relaxivity maps.