Very Fast T2* Imaging by Using Improved Echo-Shifted Gradient-Recalled-Echo (iESGRE)

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INTRODUCTION Echo-Shifted Gradient-Recalled-Echo (ESGRE) can be used to rapidly acquire MR images with strong T2* sensitivity [1, 2]. In this approach, excited spins are precessing over multiple TRs before each gradient echo is recalled. Therefore, the effective T2* weighting period in ESGRE is longer than one TR (TE>TR). This property makes it attractive in various clinical applications to significantly reduce scan time, such as volumetric T2* brain imaging and bolus tracking [1-4]. However, in most of reported applications, only one TR was shifted since the original ESGRE approach tends to produce strong ghosting artifacts for multiple-TR shift. Here, we demonstrate an improved ESGRE (iESGRE) method, which can be used to acquire ghosting free T2* images with an arbitrary echo shift index.

METHODS The pulse sequence of ESGRE is shown in Fig 1. An additional crusher gradient (Gc1) is applied prior to the readout gradient in each TR. By carefully choosing the area of these crushers, each primary gradient echo can be recalled during the *(n+1)*th TR instead of the immediate one, where *n* is the desired shift index. If *n* is equal to one, the pattern of crusher gradients has a period of two TRs, with Area_Gc1 = [A, -A, A, -A …], where A is a constant that has to be large enough for sufficient spoiling. As *n>1*, the crusher area pattern should always have a period of *n+1*, but the solution is not unique. For example, if *n=2*, we can use Area_Gc1 = [A, 2A, -3A, A, 2A …] (Fig 1); if *n=3*, one design may be Area_Gc1 = [A, 2A, 4A, -7A, A, 2A …] [1]. Although these crusher designs would truly delay the primary gradient echoes by desired shift indices, using different crusher areas (*n>1*) during each TR may cause ghosting artifacts in imaging. It is because periodical crushing will produce periodical steady-states in signal amplitudes (Fig 2). In addition, these view-varying crushers can also induce inconsistent eddy-currents to different phase encodes. Here we propose an iESGRE method to implement multiple-echo shift while maintaining a single steady-state among all TRs. This can be accomplished by inserting one more crusher gradient after the readout gradient within each TR, as shown in Fig 1 (Gc2). To achieve a desired shift index, the new crusher gradient pattern should be solved as Area_Gc2 = [(A, -(*1+1/n*)A), (A, -(*1+1/n*)A) …]. These crushers are usually combined with z-gradients.

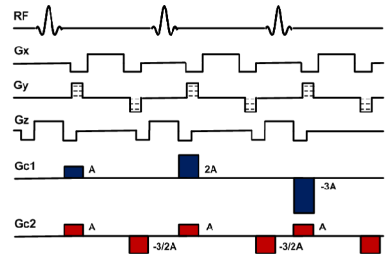

Figure 1: A 2D pulse sequence of ESGRE (and iESGRE) with a shift index of 2. Without crushers, gradients on all three axes should be completely balanced in each TR. Gc1 is the crusher gradient used in ESGRE and Gc2 is that of iESGRE.

RESULTS Fig 3 shows some phantom scan results on a 1.5T GE scanner. Three 2D pulse sequences have been used for comparison: GRE, ESGRE and iESGRE. The following scan parameters were used: FOV=24cm, Matrix-Size=128x128, Slice-Thickness=5mm, nSlice=1. For GRE, TE/TR=70/100ms, FA=10. For ESGRE and iESGRE, TE/TR=10/20ms, FA=10, *n*=3. (Effective TE is also 70ms.) A crusher pattern of [A, 2A, 4A, -7A, A, 2A …] was used in ESGRE. Images acquired at a single NEX by using ESGRE, iESGRE and GRE are shown in Fig 3A, 3B and 3C, respectively. The scan time of ESGRE/iESGRE was around 3s and that of GRE is around 13s. To make a fair comparison of SNR, an iESGRE image of 5 NEX was also acquired, which is shown in Fig 3D.

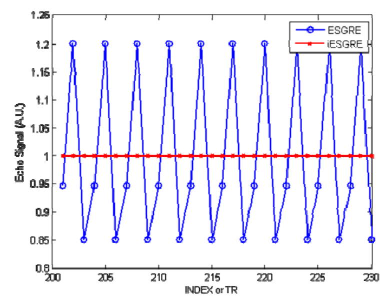

Figure 2: Simulation of the steady-states established from ESGRE and iESGRE. Simulation parameters: TE/TR=10/20ms, T1/T2*=800/40ms, FA=15, *n*=2. Magnitudes of refocused echoes are plotted after a steady-state has been established.

DISCUSSION Fig 3 has shown clearly that iESGRE makes significant improvement over ESGRE in eliminating ghosting. As a coherence-pathway selected (short TR) pulse sequence, there is always signal loss due to insufficient relaxation. In another word, there has to be a tradeoff between image SNR and scan time (echo shift index) in iESGRE. In most of its applications such as volumetric scans, we would rather trade a shorter scan time by losing some image SNR, especially at high fields. In iESGRE, the maximum signal can be approximately achieved by finding an optimal flip angle from Eq 1 based on a prediction of T1 and T2*. There is another advantage of iESGRE over ESGRE when we look at the signal composition from a view of coherence pathways. The existence of post-readout crushers totally eliminates all of the possible stimulated spin echoes, which may compromise the T2* contrast in ESGRE.

$$|My_{TE}| = M_0 \int_0^{2\pi} \frac{E_{2E}(1-E_1)\sin\alpha[-E_2\sin\phi\sin\phi_a+(1-E_2\cos\phi)\cos\phi_a]}{(1-E_1\cos\alpha)+E_2^2(\cos\alpha-E_1)-E_2(1-E_1)(1+\cos\alpha)\cos\phi} d\phi \qquad (1)$$

Here $E_1 = -\exp\left(\frac{TR}{T1}\right)$, $E_2 = -\exp\left(\frac{TR}{T2^*}\right)$, $E_{2E} = -\exp\left(\frac{TE}{T2^*}\right)$, respectively. α is the flip angle. $\phi = \frac{\gamma}{2\pi}\int Gc(\tau)d\tau$ is the sum of both crusher areas in each TR. And $\phi_a = \frac{\gamma}{2\pi}\int Gc_a(\tau)d\tau$ is the area of the front crusher gradient. It can be replaced by using the relationship $\phi_a = -n\phi$. M_0 is simply the longitudinal magnetization at the equilibrium state.

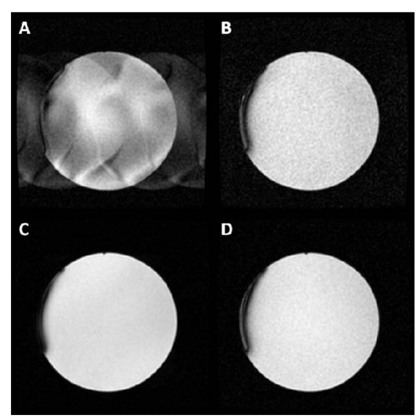

Figure 3: Phantom images at 1.5T: A-ESGRE; B-iESGRE; C-GRE; D-iESGRE(NEX=5). Measured SNR: B-22; C-83; D-47.

CONCLUSION In this work, we have demonstrated an improved method for echo-shifted T2* imaging. 2D/3D iESGRE can also be combined with parallel imaging techniques to further reduce scan time. With a significant boost of scanning speed, various clinical applications, including susceptibility imaging, functional imaging and bolus tracking, may benefit from this approach.

REFERENCE 1. Woonen C T., et al., Magn Reson Med, 26: 184-189, 1992; 2. Liu G., et al., Magn Reson Med, 0: 68-75, 1993; 3. Liu G., et al., Magn Reson Med, 30:764-768, 1993; 4. Klarhofer M., et al., Magn Reson Med, 50: 830-838, 2003;

ACKNOWLEGEMENT NCRR P41 RR09784, R01 NS047607-05, R01 NS066506-01, 5K99EB007182-02, Lucas Foundation, GE HealthCare.