Ultrashort TE 3D Gradient-Echo Imaging of Human Knee at 3T

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Introduction: In the musculoskeletal (MSK) system, connective tissues such as menisci, tendons, and ligaments, as well as hard tissues like cortical bones and calcifications contain a majority of short T_2 components. Whereas conventional imaging techniques can hardly detect signals from such short T_2 components, ultrashort echo-time (UTE) imaging (1,2) and sweep imaging with Fourier Transformation (SWIFT) (3) can capture signals well from very short T_2 components because the delay between excitation and signal acquisition is very short in these techniques, i.e., in the range of 0.01 ~ 0.5 ms. However, despite the great advantage of these techniques in imaging ultrashort T_2 species, it can be challenging to implement them on standard clinical scanners due to high technical demands such as large peak B_1 power and high gradient performance in UTE, and short T/R switching and short coil ring down time in both UTE and SWIFT. Recently, we proposed a new ultrashort TE 3D imaging technique that can effectively cover the short TE range of > ~0.2 ms (4). It was originally dubbed SWIFT-LiTE (SWIFT with Limited TE), but it is renamed here UTE-GRE (UTE GRadient-Echo imaging) to emphasize that a conventional selective pulse like a sinc pulse, as well as a frequency-modulated (FM) hyperbolic-secant (HS) pulse, can be used for excitation in practice. In this study, UTE-GRE was implemented and tested on a clinical 3T system and preliminary data of *in vivo* human knee were acquired focusing on the menisci.

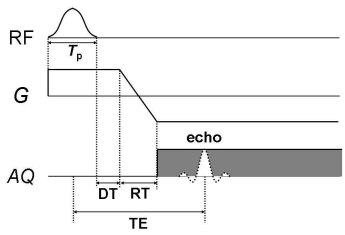

Fig.1 Sequence diagram of UTE-GRE

Methods: As shown in Fig.1, the most important feature of UTE-GRE is that the initial dephasing gradient for readout is applied during excitation and a gradient echo is acquired instead of free induction decay (FID) as in UTE and SWIFT. Any selective RF pulse can be used to excite a low tip angle in the presence of the gradient, provided the pulse bandwidth is sufficient to excite a slab wider than the largest object dimension. When a conventional amplitude-modulated (AM) pulse (e.g., a sinc pulse) is used for excitation, certain conditions must be satisfied to prevent the echo from occurring during the gradient ramp. When compared to the HS pulse, the practical peak B_1 limit is reached much sooner with the AM pulse, and thus, the slab-selective gradient needs to be smaller than the readout gradient. As the slab-selective gradient decreases, the gradient echo moves toward the ramp of the readout gradient, and as it is further reduced the top of the echo eventually occurs during the ramp period. For example, if a sinc pulse with 5 lobes is used for excitation, the condition to be satisfied to avoid echo formation during the gradient ramp is $SW^2 - BW^2 < 6\gamma R_{slew} FOV$, where SW is the readout bandwidth [Hz], BW is the pulse bandwidth [Hz], γ is the gyromagnetic ratio [Hz/gauss], R_{slew} is the gradient slew rate [gauss/s], and FOV is the field-of-view [cm]. In UTE-GRE, radial sampling is typically performed with isotropic angular spacing to cover a sphere in k-space, having a spiral shape of view orders (5).

Experiments: UTE-GRE imaging was performed on 3T Trio scanner (Siemens, Erlangen, Germany). Imaging of healthy human volunteers was performed according to the procedure approved by the Institutional Review Board. RF transmission and reception were performed with a birdcage knee coil (Siemens "CP Extremity"). The HS pulse had the following parameters: pulse length (T_p) = 0.25 ms, BW (= SW) = 80 kHz, and flip angle = ~4°. Data were acquired with different TE values (= 0.4, 1.2, and 2.0 ms). Scan time = ~8 min. Fat was suppressed by applying a fat-selective preparation pulse between every 32 acquisitions. The spherical FOV (= slab width) = 25 cm. Isotropic resolution = 0.6 mm^3. 4 spirals of view orders were interleaved to generate 144,000 projections with NEX = 1. For image reconstruction, data were re-gridded onto Cartesian coordinates and Fast Fourier transformation (FFT) was performed after Gaussian filtering.

Results and Discussions: UTE-GRE was successfully implemented and tested on a clinical 3T scanner, and it produced high quality knee images. Figure 2 shows examples of UTE-GRE knee images acquired with TE = (a) 0.4 ms, (b) 1.2 ms, (c) 2.0 ms. With all three *TE*s, UTE-GRE provided good sensitivity to visualize both anterior and posterior horn medial menisci (AHM and PHM) and articular cartilage (AC). The SNR and the relative contrast of tissues of interest were measured in these images (Table 1 and 2). As TE increased, the SNR of each tissue decreased with a different rate. Since the T_2 of the meniscus (= ~10 ms) is shorter than the AC (= ~35 ms), the SNR of the menisci decreased faster than the AC and the contrast between the AC and the menisci increased. It is notable that the SNR of the red zone (RZ) decreased much faster than the white zone (WZ). The contrast between WZ and RZ was maximal with TE = 1.2 ms. To the best of authors' knowledge, this is the first study to differentiate between WZ and RZ without a contrast agent or image subtraction. When the contrast between AC and menisci is also considered, the image with TE = 2.0 ms seemed to be the best in terms of overall contrast. In summary, UTE-GRE shows much promise to become a useful sequence for MSK imaging.

Table 1: SNR (±S.D.) of tissues of interest

TE (ms)	Articular cartilage (AC)	Posterior horn medial meniscus (PHM)		Anterior horn medial meniscus (AHM)
		White zone (WZ)	Red zone (RZ)	
0.4	83.5±0.9	71.9±1.2	70.7±1.9	67.0±1.3
1.2	81.8±1.7	70.3±0.8	57.9±1.5	62.1±1.9
2.0	80.8±1.1	64.9±1.3	55.7±1.8	56.8±2.2

Table 2: Relative contrast between tissues of interest

TE (ms)	Contrast (%) (AC – PHM)	Contrast (%) (AC – AHM)	Contrast (%) (WZ – RZ)
0.4	16.1	24.6	1.7
1.2	16.4	31.7	21.4
2.0	24.5	42.3	16.5

References: (1) Pauly et al., 8th ISMRM (1989): p.28 (2) Glover et al, JMRI 2 (1992): 47-52 (3) Idiyatullin et al., JMR 181(2006):342-349 (4) Park et al., 17th ISMRM (2009): #253 (5) Sam, et al., MRM 32(1994):778-784 **Acknowledgement**: NIH grant P41 RR08079.

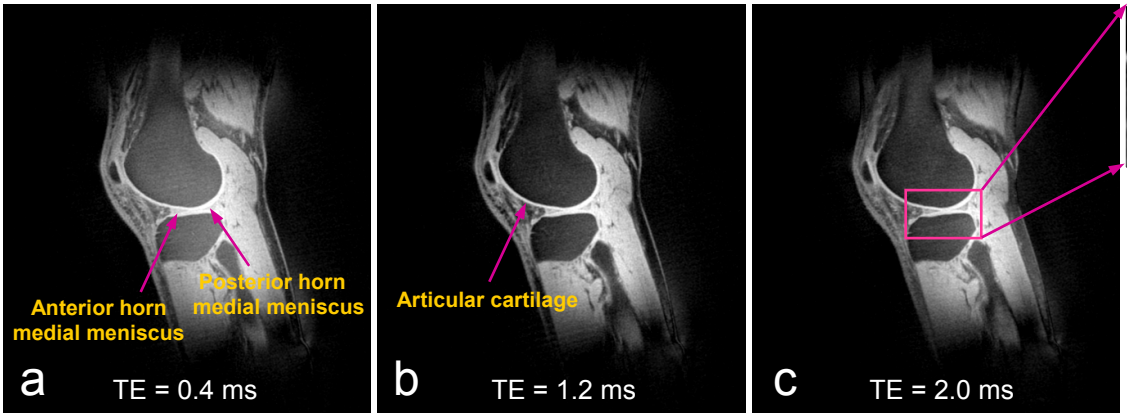

Fig. 2 Sagital images of in vivo human knee using UTE-GRE imaging with fat suppression. Data were acquired with a different TE = (a) 0.4 ms, (b) 1.2 ms, and (c) 2.0 ms.