Rapid, High-Resolution, and Multi-Contrast Knee MRI of Short T_2 Tissues with Ultrashort TE Double-Echo Steady-State

Akshay S Chaudhari[1,2], Catherine J Moran[2], Emily J McWalter[2], Garry E Gold[1,2], and Brian A Hargreaves[1,2]

[1]*Bioengineering, Stanford University, Palo Alto, California, United States,* [2]*Radiology, Stanford University, Palo Alto, California, United States*

Target Audience: Clinicians and Physicists interested in MSK & UTE

Introduction: MR imaging of connective tissues in the knee, such as menisci, tendons, and ligaments, is challenging due their short T_2 relaxation times. Ultrashort TE (UTE) imaging techniques that offer echo times of <1ms, have been implemented to image such short T_2 species[1]. However, the proton-density (PD) contrast of UTE images leads to minimal contrast between such tissues. The double-echo steady-state (DESS) pulse sequence has been used to produce multi-contrast images in the knee, but the imaging of short T_2 tissues remains a challenge[2]. We developed multi-echo UTE-DESS, which offers rapid and high-resolution imaging of short T_2 tissues with PD, T_2, and diffusion contrasts, along with fat-water separation and a very high overall scan efficiency. In this work, we present initial results from the use of multi-echo UTE-DESS for examination of short T_2 connective tissues in the knee.

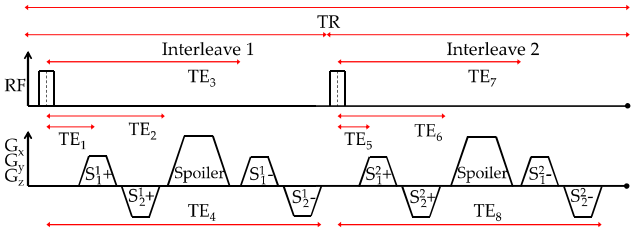

Figure 1: Multi-echo UTE-DESS produces 2 free induction decay readouts (S+) and the spoiler helps create 2 diffusion weighted readouts (S-) per interleave. Two interleaves with varied echo times are played out sequentially, to produce a total of 8 echoes.

Methods: DESS was modified to include a non-selective excitation and 3D UTE radial readouts. The UTE radial acquisitions allow rapid imaging of short T_2 components with sub-millimeter isotropic resolution. The two DESS echoes include a T_1/T_2 weighted first echo (S+) and a more T_2 and diffusion-weighted second echo (S-). Additional echo times for fat/water separation were obtained by placing inverted readout gradients after S+ and S-. The same sequence with varied timing parameters was played out in a sequential manner every TR, to yield a total of 8 echoes (Fig. 1).

Seven healthy volunteers were scanned with both UTE-DESS and Cartesian DESS on a GE MR 750 3.0T MRI scanner (GE Healthcare, Milwaukee, WI) with a 16-channel knee coil (NeoCoil, Pewaukee, WI). 3D UTE-DESS imaging with 1 cycle/pixel spoiling was performed over a 160mm FOV with a matrix of 320, resulting in an isotropic resolution of 0.50mm. A 10°, 28μs non-selective hard pulse was used with a receive bandwidth of ±250kHz. 39,288 spokes with a TR of 6.2ms were acquired for 8x undersampling, for a total scan time of 7:22. The 4 S+ echoes (TE = 48μs, 950μs, 1772μs and 2674μs) were used to generate fat and water separated images using a graph cut technique[3]. Long T_2 subtraction images were created by subtracting the S+ and S- echoes. The Cartesian DESS parameters were: FOV = 160mm, 256x256 matrix, 3mm slice thickness, TE/TR = 9/25ms, bandwidth = ±31.25kHz. SNR between Cartesian DESS and UTE-DESS was compared in the medial meniscus, posterior cruciate ligament (PCL), patellar tendon, and articular cartilage. Image noise was measured by reconstructing images while the RF excitation was disabled. Differences in SNR were compared using a Wilcoxon signed rank test.

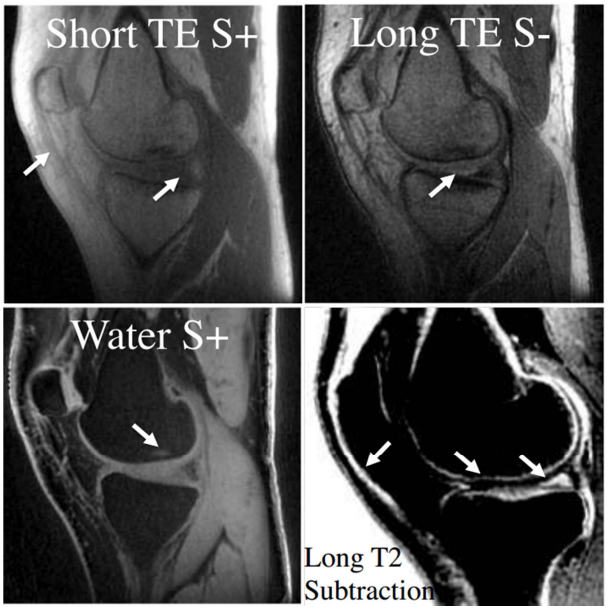

Figure 2: UTE-DESS echo 5 and 3 images, a S+ water only image, and a subtraction image between echoes 5 and 3.

Table 1: SNR comparisons between DESS and UTE-DESS, and p-values for H_0: $SNR_{UTEDESS} > SNR_{DESS}$

Tissue	DESS SNR	UTE-DESS SNR	p-value
Medial Meniscus	8.0 ± 1.5	21.8 ± 5.0	0.0078
PCL	12.5 ± 2.2	22.5 ± 9.0	0.0234
Patellar Tendon	3.6 ± 1.1	16.0 ± 6.6	0.0078
Articular Cartilage	23.6 ± 2.9	28.4 ± 7.8	0.1456

Results and Discussion: The short-TE S+ (TE = 48μs) image (Fig. 2) has PD contrast and T_1 weighting, and shows high signal from the meniscus and patellar tendon (arrows). The long-TE S- image (Fig. 2) includes additional T_2 weighting and a minimal diffusion weighting from the spoiler, which overall shows increased fluid signal around the posterior horn of the meniscus (arrow). Higher diffusion weighting for S- echoes can be imparted by increasing the spoiler area. Additionally, the four S- echoes can be RMS combined to provide a high SNR even in the presence of strong diffusion gradients. The fat/water-separated images (Fig. 2) show the presence of a bone marrow lesion (arrows). The long-T_2 subtraction image (Fig. 2) shows isolated signal from short T_2 tissues such as patellar tendon, meniscus, and cortical bone (arrows). UTE-DESS produced a higher SNR than DESS in the medial meniscus, patellar tendon, and PCL for $p < 0.01$, < 0.01, and < 0.05 respectively (Table 1). While the radial sampling does incur a SNR efficiency penalty, it does not create significant artifacts[4]. The short TR and a sampling duty cycle of 65% led to excellent SNR efficiency and minimized scan time. Based on voxel size and scan time, we would expect the UTE-DESS SNR numbers to be 5.7x lower, but they are higher due to the very high efficiency of UTE DESS for SNR of short T_2 tissues.

Conclusions: The UTE-DESS sequence shows its capability to generate high-resolution images of short T_2 tissues of the knee, with PD, T_2, and diffusion contrasts along with fat and water separated images. This rapid sequence is promising for routine study of the connective tissues in the knee.

References: 1) Robson et al, J Comp Assist Tomogr, 2003; 2) Staroswiecki et al, MRM, 2012; 3) Hernandao et al, MRM 2010 ; 4) Peters et al, MRM, 2000. **Acknowledgements**: NSF DGE-114747, NIH, and GE Healthcare.