Ultra Short TE (UTE) Imaging at 8 μsec with 3D Vastly Undersampled Isotropic Projection Reconstruction (VIPR)

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Introduction: Biological tissues contain components with a broad range of relaxation times. Many musculoskeletal tissues including cortical bone, menisci, tendons, and calcified cartilage have T_2s ranging from 100s of microseconds to 10s of milliseconds. Ultra-short echo-time (UTE) imaging (1-21) allows visualization of short-T_2 structures that have low or zero signal on conventional images.

The majority of prior UTE work has utilized 2D techniques with half-pulse excitations and center-out radial acquisitions (1-20). 3D UTE methods (21) offer several advantages including increased SNR, volumetric coverage with isotropic resolution, and the opportunity for shorter, non-selective RF excitations that allow less time for T_2 decay.

The delay between the end of the RF pulse and the start of the center-out acquisition (T_{fid}) is a critical performance indicator in UTE imaging . Recently, 2D UTE images have been acquired with a T_{fid} of 8 μs (15), representing an order-of-magnitude reduction from previous 1.5T implementations.

In this work, we extend our 8 μs capabilities to three dimensions (3D) using the 3D vastly undersampled isotropic projection reconstruction (VIPR) pulse sequence (22).

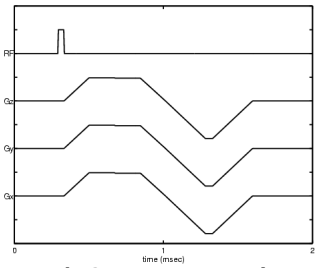

Fig. 1. The 3D Projection encoding pulse sequence with a hard excitation pulse and fully balanced gradients waveforms. The minimum achievable echo time is 8μs.

Methods: Figure 1 depicts our 3D UTE pulse sequence implemented on a 1.5T Signa TwinSpeed (GE Healthcare Technologies, Milwaukee, WI) with maximum gradient performance of 40 mT/m and 150 mT/m/ms. A non-selective excitation pulse is followed by a 3D center-out radial acquisition. T_{fid} is limited only by the time required to turn off the RF transmitter and enable the receiver. The ring-down time of an RF transmit coil can be estimated by the Q of the coil divided by its resonant frequency and is on the order of 5 μs. The 8 μs required by the pulse sequence to switch from transmit to receive is sufficient for the RF coil to dissipate transmit energy. Since the RF pulse is non-selective, the signal fall-off from a small receive coil is used to limit the FOV.

As a part of a calibration procedure to optimize image quality, Duyn's method (23) is used to measure the actual k-space trajectory produced by the acquisition gradients. The k-space trajectories are measured along the principal axes and superposition is used to estimate the trajectory of each ray in 3D k-space. There are no gradient eddy currents associated with the non-selective RF pulse.

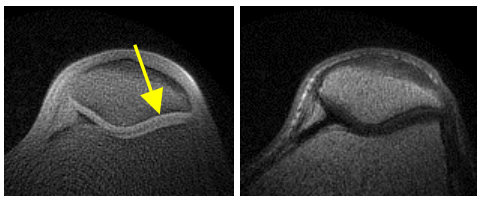

Fig. 2. 3D VIPR at 8μs. a) Fat Sat SPGR contrast b) SPGR (no fat-sat).

The pulse sequence has the option to spoil the transverse magnetization with gradient and RF spoiling (SPGR) or to refocus gradients and generate SSFP contrast. In SSFP mode, the phase-cycled, linear combination SSFP imaging option can also be used to suppress signal from fat (22). To demonstrate the potential of our UTE method, healthy volunteers were imaged following informed consent. A 3-inch general-purpose surface coil was used for signal reception. Imaging parameters include: T_{fid}=8μs, BW=+/-125kHz, FOV=15x15x15cm^3, flip=15°, resolution=0.6x0.6x0.6mm^3. The SPGR used a TR of 2.2ms acquired 128000 rays in five minutes. Fat-saturated SPGR (FS-SPGR) used a TR of 14m to acquire 40898 rays in ten minutes. For SSFP imaging, TR was 2.0ms and resulted in two phase cycled 68180 ray sets in a single five minute scan.

Results: Figure 2 presents 3D UTE images of the knee of a healthy volunteer. Images were acquired using a) FS-SPGR and b) SPGR. Note the deep layer of calcified cartilage in the FS-SPGR image (arrow). Figure 3 shows 3D LC-SSFP water, fat, and spectral MIP images.

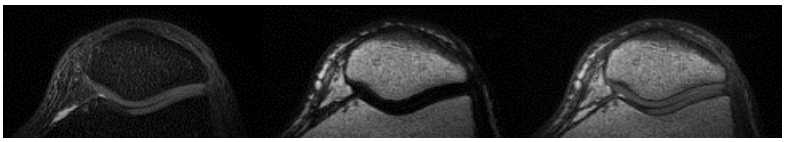

Fig. 3. 3D LC-SSFP VIPR at 8μs. With the short TR possible with the VIPR sequence, LC-SSFP contrast used to obtain short echo time SSFP water and fat images. a) LC-SSFP water image b) LC-SSFP fat image c) Spectral MIP of a) and b).

Conclusion: Our 3D-UTE imaging method achieves a excitation-readout delay of only 8 μs. This substantial reduction compared to previous 3D implementations holds promise for imaging of very short T_2 components and provides a platform for exploration of the limits of achievable resolution when imaging such tissues.

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