Implementation of a 3D Isotropic Ultra-shot TE (UTE) Sequence

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Introduction: Though very hardware demanding, it is now feasible to detect signals from tissues with short T2s using ultrashort TE (UTE) pulse sequences. Imaging at ultrashort echo times (UTE) in the order of 100 µs allows the detection of protons exhibiting very short T2 relaxation times [1]. To avoid image blurring of fast relaxing species, short data acquisition windows have to be used, which results in a low SNR. On the other hand, the tissues that typically found with short T2s, such as tendons, ligaments, or the periosteum, are normally thin and require high spatial resolution to provide any clinical results. The common choice for the UTE sequence is a combination of short RF pulse for excitation and 3D data acquisition scheme (e.g., radial trajectory) for signal detection. While compared to 2D sequence, a 3D data acquisition normally provides better SNR, however, with prolonged scan time. In practical, the short relaxation time for different tissues could well range from 100 us to 1ms. Thus, it is possible to reduce these prolonged scanner time with longer readout duration according to the targeted tissue and its corresponding relaxation properties. A typical 3D acquisition, such as radial scans, does not provide this flexibility. In this study, we implemented and demonstrated a combination of rotated spiral 3D UTE sequence that allows a trade off between the total scan time and trajectory length (that is, imaging blurring depends on the targeted T2s.)

Methods: The new 3D UTE was implemented on a Siemens 7T Trio scanner. Right after the RF excitation pulse and a 40us hardware delay, a spiral-out trajectory was played out and data acquisition started immediately. In our implementation, the excitation RF used either as non-selective rectangular RF pulses with variable durations (minimal, 60us) or slab selective RF pulses (minimal 1ms), which corresponds to a minimal 70us and 0.5ms echo time (TE), respectively. The 3D k-space was covered by a multi-segmented 2D spiral-out trajectory and then rotates this 2D spiral trajectory along a fixed axis (red line) as shown in Fig.1. To enable a high segmentation for the 2D spiral, a fast numerical spiral trajectory designed method was developed and implemented using Matlab. As shown in Fig.1, the segments for the 2D spiral can be varied from 64 to 256 for a 128×128 image matrix. When the number of segments was higher than the image matrix size, the readout duration tends to be close to the radial scan. Note, the trajectory design method proposed in Ref [2] can not be applied for such cases. The n needed umber of rotations for the 2D spiral trajectory is pi/2 if k-space shall be fully sampled. However, to shorten the total data acquisition time, the high k-space can be undersampled by setting this rotation number to a smaller number as in the radial scan. The new 3D UTE was implemented on a Siemens 7T Trio scanner. Due to fast trajectory designed method, the spiral trajectory can be real-time prescribed without delaying any user interface interaction though many spiral trajectories were generated for each UI binary search. The image reconstructions used the gridding method with a 3D Kaiser-Bessel convolution kernel (4×4×4) and were realized on the scanner with online reconstructions.

Experiments were performed on phantoms using a Siemens 7T whole-body system with an eight elements Rapids Tx/Rx coil array for reception and excitation. 3D isotropic UTE imaging of the resolution phantom was 512×512×512 matrix, FOV 256mm, 512 spiral segments and 512 rotation of 2D spiral trajectory. TR and TE were 15ms and 70us, respectively. The RF flip angle was 5°. The spiral trajecoty was designed with a maximal gradient amplitude, 34mT/m and maximal slew rates, 150mT/m/ms. The RF coil was imaged without any loading and with a larger FOV = 400mm and lower resolution (128×128×128).

Results and Discussion: Fig.2 shows the phantom image of the resolution phantom. No obvious artifacts were visible. However, with TE as short as 70us, there are some low intensity signals coming from the RF coils and padding foams. These low intensity signals can be nicely demonstrated with images without phantom. The coil structures (middle, Fig.2) were imaged with the new UTE sequence and compared well with coil itself. The T_2 relaxations of padding foams used in our lab were measured and determined to be 1.2 ms using the new UTE sequence. When the image FOV is smaller than the coil detection range, these signals could folder back into image domains. From these observations, for ultra-short TE imaging, new materials will be needed for making the coils and padding foams to avoid any interface when measuring fast relaxation components. In conclusion, we demonstrated that the 3D UTE sequence by rotating the 2D trajectory can be used for UTE imaging. Compared to 3D radial acquisition, the total scan time can be flexibly shortened by varying the spiral segments depends on the targeted relaxation properties. Applying the sequence for in vivo studies, such as knee, will be our next steps.

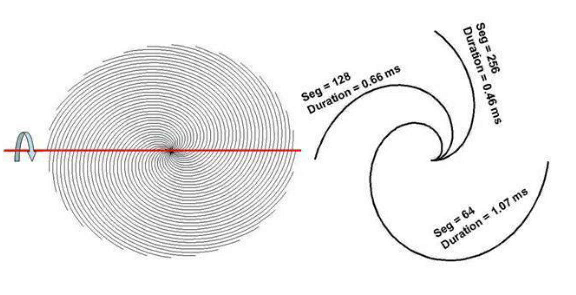

Fig. 1 The 3D *k*-space (left) was covered by rotating the 2D spiral trajectory along the fixed axis (red line). The spiral duration for 128×128 with different segments (right) was shown. The segments for the spiral can be higher than the matrix due to our new spiral design method.

References: [1] Holmes, J.E., *et al.*, Radiography; 11; 163-174. [2] Glover, G. H., *et al.*, Magn Reson Med 1999; **42**:412-415.

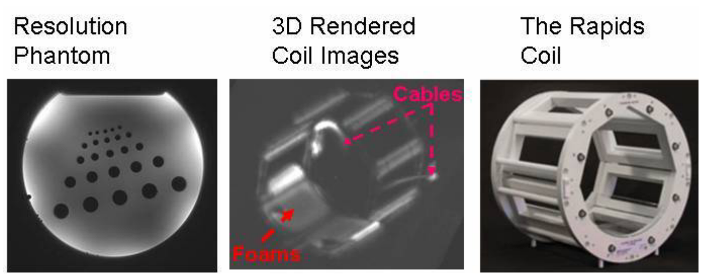

Fig. 2 UTE sequence results. Left, resolution phantom; Middle, coil structures from UTE sequence; Right, the picture of the Rapids 8-channel Tx/Rx coils.