3D Radial FID-Sampling for Ultrashort TE Imaging at 3 T

J. Rahmer[1], P. Börnert[1], C. Schröder[1], C. Stehning[2]
[1]Philips Research Laboratories, Hamburg, Germany, [2]Institute for Biomedical Engineering, University of Karlsruhe, Karlsruhe, Germany

Introduction

Ultrashort echo-time (UTE) sequences are employed to observe short-living spin species usually found in cortical bone, tendons, ligaments, menisci, and related tissue. The majority of protons in these tissues exhibits T2 relaxation times, which are too short to be detected with conventional imaging sequences. The usual 2D UTE implementation allows echo times in the order of 100 µs [1]. However, it suffers from partial volume effects as well as difficulties in the slice selection. Furthermore, the use of dedicated self-refocused half-Sinc RF pulses [2,3] requires the acquisition of at least two averages, which increases scanning time. The 3D technique presented in this contribution naturally avoids these problems.

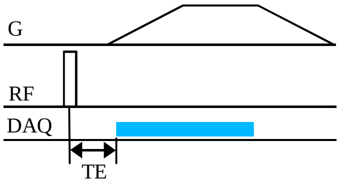

Fig. 1: 3D ultrashort TE sequence using an RF block pulse for excitation. FID sampling starts on the rising slope of the read-out gradient.

Methods

Figure 1 depicts the basic 3D UTE sequence. A non-selective block pulse is used for excitation. After a coil-dependent switching time of 60-120 µs, a 3D radial readout gradient is ramped up to sample the free-induction decay (FID) [4]. In this contribution, TE is defined as the time measured from the center of the RF pulse to the beginning of the data acquisition, which coincides with sampling the k-space origin. Thus, k-space is mapped radially starting at $k = 0$. To achieve 3D isotropic spatial resolution, the endpoints of the radial projections follow a spiral path running from one pole to the other on the surface of a sphere [5]. Due to radial k-space mapping and sampling on the gradient slopes, the center of k space is heavily oversampled, making sampling density compensation necessary prior to 3D gridding. Since RF excitation is non-selective, local receive coils with a limited sensitive volume are employed to decrease the noise level and avoid potential foldover.

Experiments have been performed on phantoms and healthy volunteers using a 3 T whole-body scanner (Gyroscan Intera, Philips Medical Systems). In some experiments, a local transmit/receive birdcage coil was used for excitation and signal sampling. This coil can be switched within 90 µs between the two modes. In other scans, the body coil was used for RF transmission and a dedicated four-element phased surface-coil array [6] was employed for signal reception. For safety reasons, the energy in the body coil has to ring down (50 µs), before the phased array is tuned (100 µs). Thus, using phased arrays the shortest possible echo times are limited. In the initial experiments performed, the excitation block RF pulse had a duration of 84 µs (not optimized for UTE). The other parameters were as follows: FOV of 300 mm and 250 mm for Fig. 2 and 3, respectively, 128×128×128 matrix, TR 10 ms, excitation angle 10°. 16384 projections have been measured using a data-acquisition window of 500 µs.

Results and Discussion

Selected in-vivo results are shown in Fig. 2 and 3. Figure 2 displays a 3D feet measurement obtained using the T/R head coil. In Fig. 3 knee data are shown, which have been detected with the phased array coil. Radial 3D UTE acquisition yields volume data with isotropic resolution, which is well suited for the visualization of complex joint structures with short T2 components. Furthermore, 3D imaging has the advantage that no slice selection with its sensitivity to field inhomogeneities and motion has to be performed. On the other hand, in comparison with 2D UTE, which uses self-refocused pulses, 3D echo times as defined above are not only limited by the switching time of the receive coils but also by the duration of the excitation pulse. However, the use of considerably shorter RF pulses is intended in the future. Beside a desirable further reduction of the echo time using shorter RF pulses and shorter coil switching times, high-resolution images of short TE components also depend on short acquisition windows to reduce T2 blurring of fast-relaxing components. This requires large gradients and high slew rates which in turn degrade the SNR. Therefore, UTE imaging in particular benefits from the high SNR offered by the high-field multi-coil approach. Figs. 2 and 3 also show a typical problem of UTE sequences: low intrinsic contrast. While this contribution is to show the basic feasibility of 3D UTE imaging, the suppression of long-T2 components will be necessary for high-contrast images.

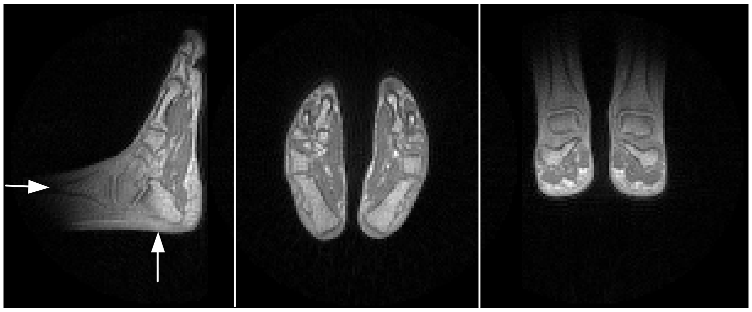

Fig. 2: Selected slices of a 3D feet dataset acquired with the 3D radial UTE sequence using a T/R head coil. The echo time as defined in the text was 130 µs, the matrix size was 128×128×128. From left to right: Sagittal slice of the right foot, transverse and coronal slice through the feet. The arrows indicate the transverse and coronal slice positions.

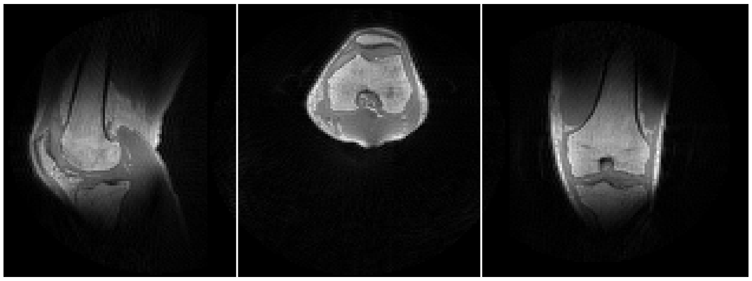

Fig. 3: Central slices of a 3D UTE data set of the right knee acquired using a 4-element phased surface-coil array. Echo time was 190 µs. A sagittal, transverse, and coronal view is displayed, respectively.

Conclusion

The potential of 3D radial FID sampling for the visualization of fast decaying spin species in complex three-dimensional structures with ultrashort echo times is demonstrated. The use of phased arrays at 3 T yields a high signal-to-noise ratio and thus enables scan time reduction by means of parallel imaging in the future.

References

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