Creating Short T2 Contrast with Three-Dimensional Ultrashort TE (3D UTE) Imaging

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Background

There is increased interest in imaging short T2 species such as the meniscii, tendons and cortical bone. These tissues show little or no signal with conventional MR sequences. Several groups have been working on three-dimensional ultrashort TE (3D UTE) sequences with TEs of 100 µs or less (1-5). Short T2 contrast is generated either with echo subtraction or one or two long 90° saturation pulses followed by gradient dephasing. Here we report on a 3D UTE sequence (minimal TE = 8 µs) using several long T2 suppression techniques including long T2 saturation, adiabatic inversion, dual echo subtraction, and combinations of these . The efficacy of these approaches was demonstrated through in vitro and in vivo imaging of meniscii, tendons and cortical bone using a 3T clinical scanner.

Materials and methods

Figure 1 shows the 3D UTE sequence which employed a short duration (40 to 80 µs) hard RF pulse for signal excitation followed by dual echo 3D radial ramp sampling. Long T2 signals were suppressed using three approaches: 1) a maximal phase 110^0 pulse (duration = 4.8 ms) followed by gradient dephasing, 2) an adiabatic inversion pulse (8.6 ms) and signal nulling, and 3) dual echo acquisition followed by echo subtraction. The last approach was also combined with the first two to further suppress residual long T2 species and improve short T2 contrast. In total ten cadaveric samples, including meniscii (n=3), tendons (n=3) and cortical bone (n=4), and five normal volunteers were studied. The acquisition parameters included an isotropic FOV of 8 cm for cadaveric samples and 16 cm for human volunteers, TR of 23 to 94 ms, TI of 38 ms (for the inversion approach only), readout of 256 to 384, projections of 20000 to 60000 in a total scan time of 15 to 24 minutes. The projection data was re-gridded onto a 384×384×384 matrix and was followed by 3D Fourier transformation to produce the final 3D UTE images.

Results and Discussion

High resolution and contrast images were achieved for meniscii, tendon and bone in all samples and volunteers. The 3D UTE sequence with a short TE of 8 µs provides excellent depiction of the meniscal fiber structures with a high SNR of 41±8 as shown in Figure 2. Figure 3 shows 3D UTE imaging of the forearm with long adiabatic inversion pulse to null signal from muscle. Signals from fat and skin were only partly suppressed because they have different T1s and cannot be nulled by a single inversion pulse. Figure 4 shows 3D UTE imaging of a small pig leg. Signals from muscle and fat were well suppressed by the maximal phase 110^0 pulse which slightly inverted long T2 water and fat magnetization and then nulled both before the 3D UTE acquisition. The residual long T2 signal was further suppressed by echo subtraction, leaving excellent contrast for cortical bone. Our preliminary results show that the adiabatic inversion approach provides more uniform (B1 insensitive) long T2 suppression but 30~40% lower SNR efficiency than the long T2 saturation approach. A flip angle of 110° seems to work more efficiently than a conventional 90° saturation pulse which typically leaves much stronger residual signal from muscle and fat. The combination of dual echo subtraction with maximal phase saturation pulse seems most promising for clinical 3D UTE imaging.
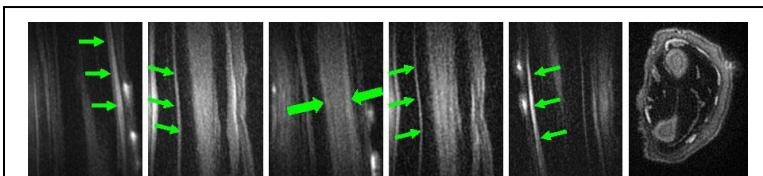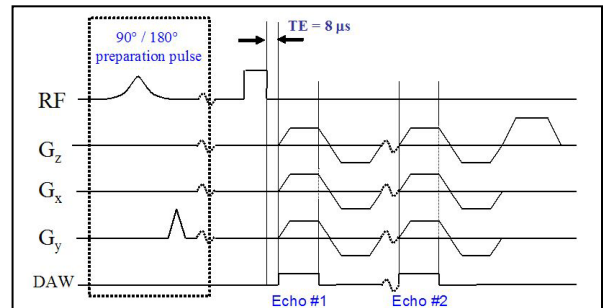

Fig 1 3D UTE sequence for imaging of short T2 species with a minimal TE of 8 µs achieved through the combination of a short hard pulse, 3D dual-echo radial ramp sampling and fast T/R switching. Long saturation or inversion pulses were employed to suppress long T2 signals from muscle and fat.
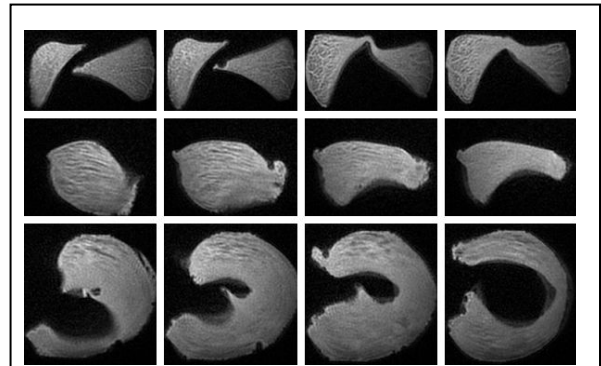

Fig 2 Selected axial (1st row), sagittal (2nd row) and coronal (3rd row) slices from 3D UTE imaging of a meniscus sample showing the meniscal fiber structures with high SNR and high isotropic spatial resolution of $0.21×0.21×0.21 \ mm^3$.

Fig 3 Selected coronal and axial slices from 3D UTE imaging of a cadaveric forearm. Long T2 signals were suppressed with an adiabatic inversion pulse which nulls signal from muscle, leaving high contrast for tendon (thin arrows). Signals from fat and skin were only partly suppressed because of their different T1s. Cortical bone is visible but with relatively low contrast (thick arrows).

Conclusion

The 3D UTE sequence provides high signal and contrast for imaging of meniscii, tendon and cortical bone, showing features which are undetectable with conventional clinical MR pulse sequences. Long T2 saturation combined with dual echo subtraction is preferred for clinical use of the 3D UTE sequence.

References

1. Techawiboonwong A, *et al.*, NMR Biomed 2008; 21:59-70.
2. Wu Y, et al., MRM 2003; 50:59-68.
3. Takahashi A, *et al.*, ISMRM 2005, p2405.
4. Larson PE, *et al.*, MRM 2006; 56:94-103.
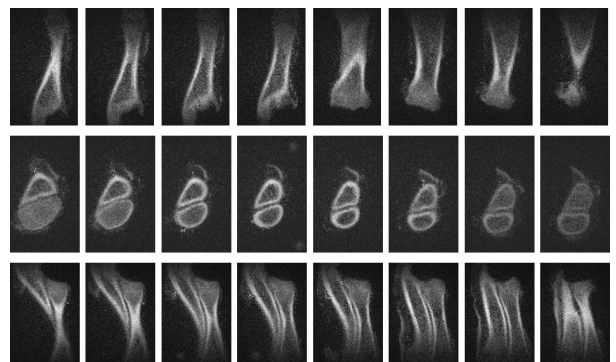5. Rahmer J, et al., MRM 2006; 55:1075-1082.

Fig 4 Selected coronal (1st row), axial (2nd row) and sagittal (3rd row) slices from 3D UTE imaging of a pig leg with a nominal acquired voxel size of $0.31×0.31×0.31 \ mm^3$. Long T2 signals from muscle and fat were well suppressed with a maximal phase 110° pulse combined with dual echo subtraction. Muscle is barely visible. There is some residual fat signal which is probably due to B1 inhomogeneity.