High Resolution 3D Ultrashort TE (UTE) Imaging: In Vivo Applications

J. Du[1], M. Carl[2], M. Bydder[1], J-T. Chiang[1], R. Znamirowski[1], C. Chung[1], and G. Bydder[1]
[1]Radiology, University of California, San Diego, San Diego, California, United States, [2]Global Applied Science Laboratory, GE Healthcare, San Diego, California, United States

INTRODUCTION

There are many species or tissue components which have very short T2 relaxation times and so cannot be detected with conventional magnetic resonance imaging (MRI) sequences (1). These include cortical bone, meniscus, ligaments, aponeuroses, the Achilles tendon, etc. High resolution in vitro imaging has been reported, together with in vivo imaging with moderate resolution and especially limited short T2 image contrast (2, 3). Here we report 3D high resolution and contrast imaging of these short T2 species in vivo on a clinical 3T MR scanner.

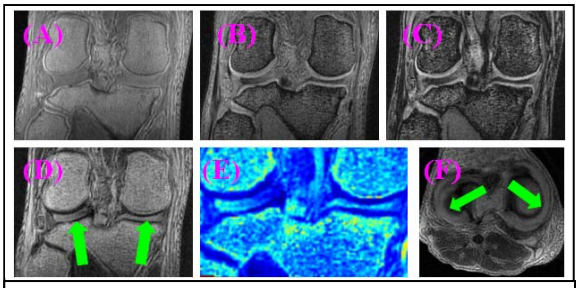

Fig 1 *A coronal slice of 3D UTE imaging of the knee with TEs of 8 μs (A), 3.6 ms (B), 7.2 ms (C),subtraction (D),R2* map(E) and an axial slice (F). Meniscus is well depicted with high isotropic resolution.*

MATERIALS AND METHODS

The 3D UTE sequence with dual echo acquisition was implemented on a 3T Signa TwinSpeed scanner (GE Healthcare Technologies, Milwaukee, WI) to image cortical bone, menisci, ligaments, aponeuroses and the Achilles tendon in ten volunteers. A short hard pulse (40 μs) was followed by 3D multi-echo (2 to 4 echoes) radial ramp sampling for data acquisition. A 3-inch surface coil or a quadrature knee coil was used for signal reception. Simple subtraction of the second image from the first may yield strong residual signal from muscle and fat, and compromise image contrast for short T2 species such as cortical bone. The combination of 2D UTE imaging with rescaled subtraction (UTE-RS) has been shown to provide high contrast for cortical bone and tendon (4). With 3D UTE-RS, the FID image is scaled down so that signals from muscle and fat become lower than those from the second echo. In the subtraction image signals from muscle and fat are negative while these from short T2 species are positive, separating them from air. The 3D UTE-RS technique can be efficient in creating high positive contrast for short T2 species, especially cortical bone which has a much lower mobile proton density than surrounding muscle and fat. The multiple echoes were also used to generate 3D T2* mapping. Typical acquisition parameters were: FOV = 20-26 cm, TE1 = 8 μs, TE2 = 2.2-4.4 ms, TE3 = 4.4-8 ms, flip angle = 9-15°, BW = 125-250 kHz, readout = 384, number of projections = 30-40 K, TR of 15 to 28 ms, total scan time 9 to 14 minutes.

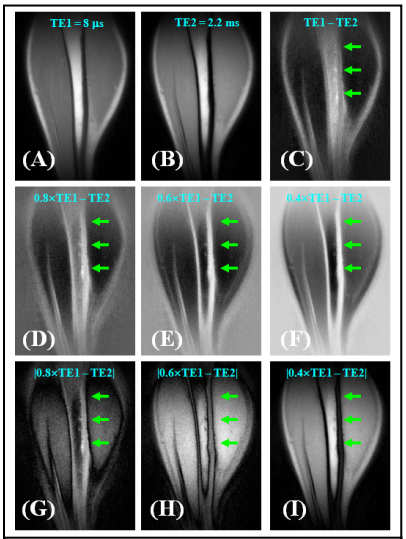

Fig 2 *A coronal slice of 3D UTE imaging with a TE of 8 μs (A) and 2.2 ms (B). Regular echo subtraction (C) provides limited contrast for tibia. Increased bone contrast was observed when negative pixel intensity was allowed and the second echo was rescaled down by a factor of 0.8 (D), 0.6 (E) or 0.4 (F). However, bone contrast gradually decreased when absolute pixel intensity was used for the same rescaling factors of 0.8 (G), 0.6 (H) and 0.4 (I).*

RESULTS AND DISCUSSION

Figure 1 shows 3D UTE imaging of the knee of a volunteer, providing high isotropic resolution ($0.6\times0.6\times0.6$ mm^3) of the whole meniscus together with R2* mapping (T2* ranges from 5 ms to 9 ms). 3D UTE imaging of tibia of a healthy volunteer (Fig 2A) provided a high SNR of 28.69 ± 4.36 for cortical bone but a negative CNR of -122.09 ± 13.39 between bone and fat, and -35.30 ± 6.57 between bone and muscle. Regular echo subtraction (Fig 2C) provided a negative CNR of -13.19 ± 3.12 between cortical bone and fat. With a rescaling factor of 0.8, 0.6, and 0.4, the UTE-RS technique increased CNR from 17.71 to 39.82 and to 65.47 between bone and fat and from 33.17 to 34.99 and to 44.31 between bone and muscle. Figure 3 shows 3D UTE imaging of the Achilles tendon of a volunteer. 3D UTE images (Fig 3A and 3E) provided a high SNR of 54.99 ± 5.73 for the Achilles tendon but a negative CNR of -26.45 ± 4.87 between tendon and fat. Echo subtraction (Fig 3C and 3G) increased CNR to 26.78 ± 3.87, which was further increased to 41.38 ± 4.14 with RS where fat signal was shifted to negative values. High resolution and contrast imaging of the aponeuroses and ligaments have also been achieved with UTE and UTE-RS in vivo. UTE IDEAL processing is expected to further improve the image quality (5, 6). The limitations include relatively long scan time, thus potential patient motion artifact.

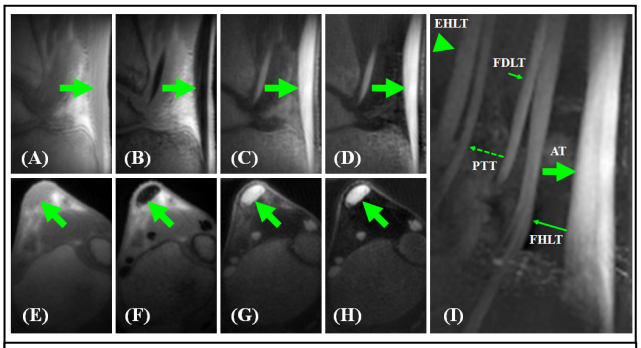

Fig 3 *Sagittal (1st row) and axial (2nd row) 3D UTE images of the Achilles tendon of a volunteer with a TE of 8 μs (A, E) and 2.2 ms (B, F). Regular echo subtraction (C, G) and rescaled subtraction with the 2nd echo scaled down by a factor of 0.6 (D, H). The sagittal MIP image (I) shows excellent depiction of the Achilles tendon (AT), the flexor digitorum longus tendon (FDLT), the flexor hallucis longus tendon (FHLT), the posterior tibialis tendon (PTT) and the extensor hallucis longus tendon (EHLT).*

CONCLUSIONS

The 3D UTE sequence combined with multi-echo acquisition and conventional or rescaled subtraction is able to provide high isotropic spatial resolution and high contrast imaging of a wide range of short T2 species in vivo under clinically acceptable scan time.

REFERENCES

1.Robson, et. al. JCAT 2003.
2. Rahmer J, et. al. MRM 2006.
2.Qian Y, et. al., MRM 2008.
4. Du J., et. al., ISMRM 2009.
5. Wang K, et. al., JMRI 2010.
6. Rahmer J., et. al., ISMRM 2010.