Musculoskeletal Imaging Using 3D Ultrashort TE Scanning at 7.0 T

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Introduction

Ultrashort echo-time (UTE) imaging is a technique to image short-T_2 components exhibiting T_2 in the sub-millisecond range. It can be used to visualize highly ordered tissues, like tendons and ligaments [1], or to reduce susceptibility-related T_2* effects, e.g. in the lung [2]. The 3D UTE technique acquires radial half-echo readouts which are reconstructed to a volumetric image data set with isotropic resolution [3,4]. At high resolution, the small isotropic voxel volume can lead to low SNR. The application of high-bandwidth signal acquisition to avoid relaxation blurring further aggravates this problem. To increase SNR, the use of higher field strength B_0 is desirable. This work demonstrates the basic feasibility of musculoskeletal imaging at 7.0 T using 3D UTE scanning, and explores whether the technique can benefit from the high signal available at this field strength. To this end, first 3D UTE dual echo scans of the hand and the ankle were performed on a 7.0 T scanner.

Methods

Figure 1(a) shows a 3D UTE dual echo sequence. After a non-selective excitation pulse and a coil-dependent switching time which determines TE_1, the readout gradient is ramped up, and the acquisition of the free-induction decay (FID) is started. *k* space is mapped radially starting at $k = 0$. After the FID, a gradient echo is acquired at TE_2. *k* space is covered in the 3D fashion depicted in Fig. 1(b) [5]. With echo times TE_1 around 50 µs, the sequence enables the detection of species with T_2* in the sub-millisecond range. If TE_2 is chosen for fat and water spins to be in-phase, an image showing only short-T_2* components can be obtained by subtracting the echo from the FID. Scanning was performed on healthy volunteers on a 7.0 T scanner (Philips Medical Systems, Cleveland, OH). A birdcage head-coil was used for RF transmission and reception. A software extension enabled 3D radial dual echo (FID/echo) scanning with immediate online reconstruction. For 3D UTE imaging, the excitation block pulse had a duration of 38.4 µs for a flip angle of 5°. FID acquisition was started at TE_1 = 50 µs. A later echo was acquired at the second water-fat in-phase echo time TE_2 = 1.97 ms. For imaging of the hand, a field-of-view (FOV) of 190 mm was reconstructed to a 176^3 matrix. 50800 radial profiles were acquired for the FID and echo, respectively. The sampling duration was 502 µs for the FID and 704 µs for the echo, with a repetition time TR = 5.6 ms. For imaging of the ankle, a FOV of 180 mm was reconstructed to a 176^3 matrix. 49560 radial profiles were acquired. Readout durations were 527 µs and 754 µs for FID and echo sampling, respectively. TR was 5.9 ms. The FID sampling window was kept short in all experiments to reduce blurring and signal loss for short-T_2 species [4]. Difference images were formed by subtracting the echo from the FID image using a scaling factor. Reformatting was applied to extract curved subvolumes from the isotropic 3D image [6].

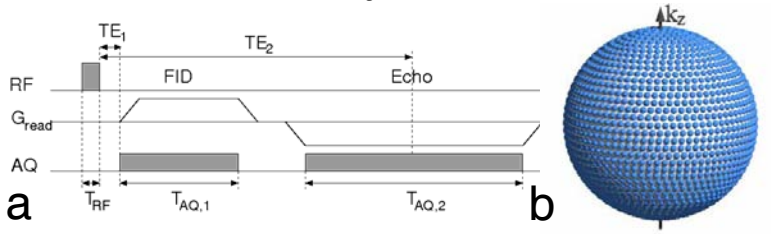

Figure 1: 3D UTE sequence. a) Ultrashort TE sequence applying a non-selective excitation pulse and an FID readout. A subsequent gradient echo is acquired in the dual echo (FID/echo) sequence. b) Distribution of radial profiles in 3D k space.

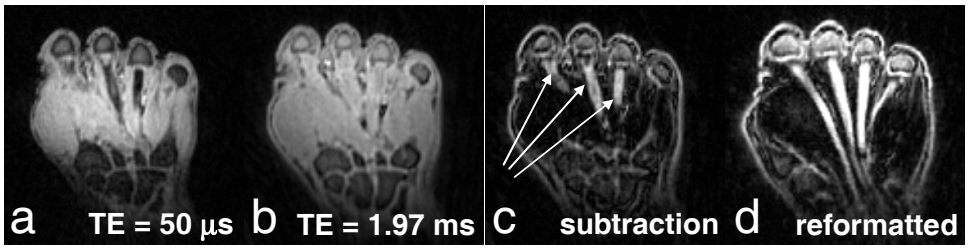

Figure 2: 3D UTE dual echo data of the right hand (fist) at 7.0 T. (a) Coronal slice from 3D FID data acquired at TE_1 = 0.05 ms. (b) Same slice from echo data acquired at TE_2 =1.97 ms. (c) Difference image between (a) and (b) showing short-T_2 components only. The finger flexor tendons yield bright signal (arrows). (d) Reformatted slice extracted from 3D difference data, delineating the tendons.*

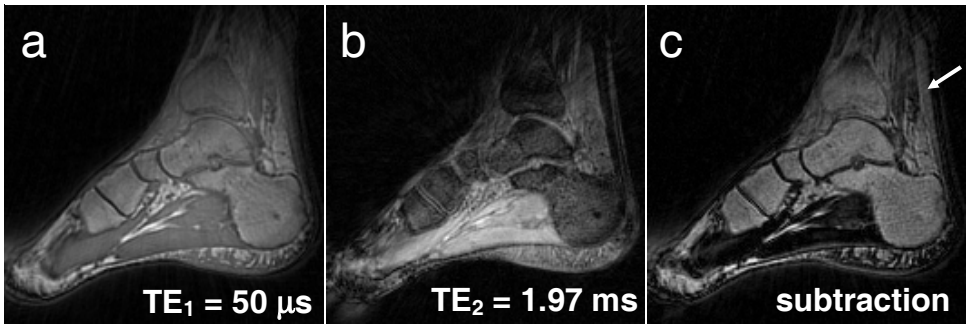

Figure 3: 3D UTE dual echo data of the right ankle at 7.0 T. (a) Sagittal slice from 3D FID data acquired at TE_1 = 0.05 ms. (b) Same slice from echo data acquired at TE_2 =1.97 ms. (c) Difference image between (a) and (b) showing short-T_2 components only. Bright short-T_2* signal not only arises from the Achilles tendon (arrow), but also from the bulk region of the bones.*

Results and Discussion

Figure 2 shows a slice of the hand, extracted from FID (a), echo (b), and difference data (c). Good image quality was obtained with high SNR. A very good contrast-to-noise ratio was achieved for the finger flexor tendons as underlined by the reformatted slice shown in Fig. 2(d). Figure 3 shows a slice from FID (a), echo (b), and difference (c) data of the ankle. The Achilles tendon (arrow) shows up in the difference image due to its short T_2, but also the bone signal is subject to substantial decay between FID and echo. This is in contrast to findings at 1.5 and 3.0 T, where bones of the ankle show hardly any short-T_2* contrast, even at longer TE_2 [4]. In general, one expects that the T_2* observed for tendons is dominated by T_2, which results from rather field-independent intrinsic dipolar interactions. Therefore, tendons show a similar relaxation behavior at 7.0 T and at lower field. However, T_2* effects resulting from susceptibility differences or chemical shift dispersion (such as for fat) scale with the field. This explains stronger fat signal decay at higher field. Our results indicate that T_2* of the bone marrow is shortened considerably at high field. We speculate that susceptibility effects related to the porous structure of the larger bones add to the chemical shift dispersion of fat to cause this effect. However, further, quantitative experiments are necessary to verify this preliminary finding.

Conclusion

3D UTE imaging can benefit from the high SNR available at 7.0 T without substantial degradation in image quality. Dual echo filtering used to highlight short-T_2* components shows rather similar T_2 for tendons compared to lower field strengths (3.0 T and 1.5 T), while T_2* in marrow-rich bones like in the ankle is substantially shortened at 7.0 T.

References

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