Merging UTE Imaging, Water-Fat Separation, and T_2^* Mapping in a Single 3D MSK Scan

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Introduction

The separation of water and fat signal contributions, e.g. be achieved by chemical shift encoding [1], is essential for a number of MSK applications to improve image contrast for clinical diagnosis. Also, ultrashort echo time (UTE) imaging [2,3] was proposed for MSK MRI, yielding extra information about short T_2 species. It is the idea to incorporate both approaches into a multi-echo imaging (ME) sequence, which samples the UTE signal in the first echo and simultaneously delivers water-fat separation, T_2^* mapping [4], and short T_2 contrast [5]. Wang *et al*. [6] recently showed a similar approach, which uses single slice imaging where each echo data set is acquired in a separate scan. In the present study, an efficient 3D ME technique is proposed, with isotropic spatial resolution, allowing the generation of water-fat separated images containing short-T_2^* components while extending the T_2^* mapping range down to $T_2^* \sim 1$ ms. The 3D approach eases planning and bears the potential of delivering comprehensive diagnostic information by means of a single scan. We apply the technique to imaging of the knee, where short-T_2 components are found in tendons, ligaments, and menisci.

Methods

Figure 1 depicts the 3D UTE/ME sequence. After non-selective excitation, the free-induction decay (FID) is sampled followed by a series of 3D radial gradient echoes. A spherical *k*-space volume is covered. A first TE < 100 µs enables the detection of species with T_2 in the sub-millisecond range, while a short echo spacing allows short-T_2^* mapping and water-fat separation.
In-vivo data of the knee were acquired on healthy volunteers using a clinical 1.5 T whole-body scanner (Achieva 1.5T, Philips Healthcare, The Netherlands) and a two-element receive array (coil ∅ 12cm) with a T/R switching time of 50 µs. A software extension enabled 3D radial FID/ME scanning with immediate online image reconstruction. FID acquisition was started at TE_1 = 60 µs after the 10° excitation block pulse. To enable T_2^* mapping, six gradient echoes were acquired with an echo spacing of ΔTE = 1.3 ms. The FOV of (160 mm)³ was covered with a 112^3 matrix. 17583 projections were acquired for each echo. The repetition time was TR = 15.0 ms, resulting in a total scan duration of 4.5 minutes. IDEAL water-fat decomposition [1] with simultaneous T_2^* estimation [4] as well as image subtraction for short-T_2 contrast [5] were applied to the reconstructed images.

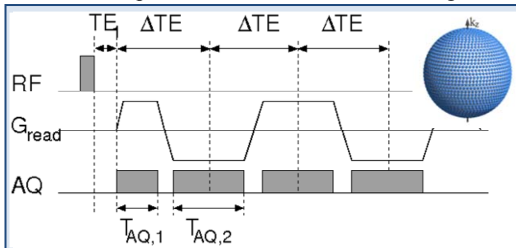

Fig. 1: 3D UTE/ME sequence. A radial 3D ultrashort TE sequence is combined with multi-echo sampling. The distribution of radial profiles in 3D *k* space is illustrated.

Fig. 2: Selected slice of a 3D isotropic data set at different TEs. Contrast changes reflect water-fat signal evolution and T_2^* decay. (Only 6 of the 7 echoes are shown).

Results and Discussion

Figure 2 shows a sagittal slice of the 3D echo series. The first image was acquired at ultrashort TE, thus showing high signal from all tissue components. An algorithm combining IDEAL with T_2^* estimation [4] simultaneously yielded high-SNR 3D water-fat data (Fig. 3a,b) as well as R_2^* maps (Fig. 3d,e). Since the first echo is acquired at UTE, the map derived from all echoes (Fig. 3d) comprises very short T_2^* components down to about 1 ms, as indicated by the brightly colored pixels found in tendons, menisci, and cortical bone. For comparison, the T_2^* analysis using only 6 echoes, excluding the FID, is shown in Fig. 3e. To selectively highlight short-T_2 components, an image subtraction between the FID and an in-phase echo was calculated (Fig. 3c). Further post-processing steps are conceivable: the separated fat signal can be used to suppress fat in the original UTE image to further improve its contrast and the ΔB_0 map delivered by IDEAL can be used to de-blur all the individual images (FID and echoes) from adverse off-resonance effects [6,7]. Additionally, corresponding in-phase and out-of-phase images can be reconstructed to ease acceptance by radiologists.

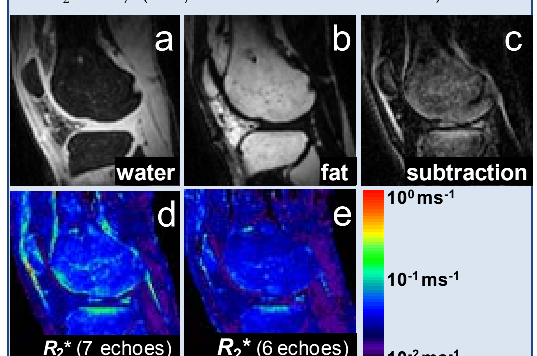

Fig. 3: Images derived from a 3D echo series. (a) water, (b) fat image, (c) difference image between the FID and a later in-phase echo, selectively highlighting short-T_2 components. (d) R_2^* map: derived from FID and 6 echoes. (e) R_2^* map derived from 6 echoes (TE = 1.3 - 7.7 ms).

Conclusion

The combination of 3D radial multi-gradient-echo acquisition with an FID acquisition at ultrashort TE extends the range for T_2^* mapping and image contrasts down to roughly 1 ms without significant increase in scan time. Additionally, this approach allows the generation of high-SNR water and fat images, which improves contrast and potentially enables a comprehensive examination by means of a single scan. The UTE/ME combination can be useful for visualization of short-T_2 tissues like tendons, yielding complementary information to conventional MSK imaging. Due to the UTE functionality, this approach may also find applications in quantitative imaging of iron particles or iron depositions which decrease T_2^*. Further studies are needed to proof the clinical value of the 3D UTE/ME approach.

References

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