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 $T_2^*$ ~ 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 Ø 12cm) with a T/R switching time of 50 µs. A software extension enabled 3D radial FID/ME imaging with simultaneous image reconstruction. FID acquisition was started at TE1 = 60 µs after the 10° excitation block pulse. To enable $T_2^*$ mapping, six gradient echoes were acquired with an echo spacing of $\Delta TE = 1.3$ ms. The FOV of (160 mm)$^3$ was covered with a 112 3 matrix. 17583 projections were acquired for mapping, six gradient echoes were acquired with an echo spacing of $\Delta TE = 1.3$ ms. The FID was acquired at 160 mm$^3$, and the echo spacing was 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.

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 $\Delta B_0$ 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.

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