Water selective high resolution imaging of short T2 components of the knee at high and ultra high field strenghts

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INTRODUCTION: Imaging of short T2 components, such as menisci and ligaments, has become a major research focus in musculoskeletal (MSK) imaging [1]. Commonly, ultra short echo time (UTE) sequences [1,2] can produce signal from short T2 components but require long reconstruction times and are sensitive to the gradient system imperfections [3]. Here, we show that a common spoiled gradient echo sequence (SPGR) can be adapted to yield sub-millisecond echo times (TE) for high resolution MSK imaging of short T2 components within clinically acceptable scan times. Sub-millisecond echo-times could be achieved using a variable echo time scheme [4, 5, 6] in combination with a highly asymmetric Cartesian sampling. In contrast to common UTE imaging, this offers the possibility to integrate additional preparation schemes, such as spectral-spatial pulses in order to achieve fat suppression. The benefits of sub-millisecond SPGR imaging were explored on a standard high field 3T MR system, as well as for ultra high field 7T MR imaging.

METHODS: The first echo time of a standard double-contrast 3D SPGR sequence was minimized by (i) a dynamic adjustment of the echo time towards the center of k-space while keeping the bandwidth constant [4, 5, 6], (ii) using highly asymmetric readouts with standard Cartesian sampling, and (iii) using optimized gradient performance and switching times. Images from asymmetric dataset were reconstructed using a POCS algorithm [7]. This allowed effective echo times (at the k-space center) down to about 800µs for resolutions down to about 500µm. Generally, sub-millisecond TE 3D SPGR images of the knee joint were acquired with water selective binomial RF pulses.

At 3T, sagittal images (40 slices) were acquired with $0.5\times0.5mm^2$ in-plane resolution and 2.5mm slice thickness. The first echo had an effective TE of 800µs (and 1.28ms at the outer k-space) using a 13% asymmetric readout, whereas the second echo was acquired with a TE = 8.22msec using a symmetric, i.e. full) readout. The bandwidth was 530 Hz/ Pixel, the TR was 15 ms and a flip angle (FA) of 9° was used. Two averages were taken yielding a total acquisition time of 5.07 min. At 7T, sagittal images (120 slices) were acquired with $0.36\times0.36mm^2$ in-plane resolution and 1.0mm slice thickness. The first echo had an effective TE of 950µs (and 1.66 ms at the outer k-space) using a 12% asymmetric readout, whereas the second echo was acquired with a TE = 8.08msec using a symmetric, i.e. full) readout. The bandwidth was 345 Hz/ Pixel, the TR was 13 ms and a flip angle (FA) of 8° was used. Two averages were taken yielding a total acquisition time of 7.51min.

RESULTS: The lateral meniscus could be clearly visualized at 3T and 7T after subtraction of the second from the first echo in the 3D SPGR images (Fig.1C, 2C), as well as other short T2 components, such as the quadriceps femoris tendon and the patellar ligament.

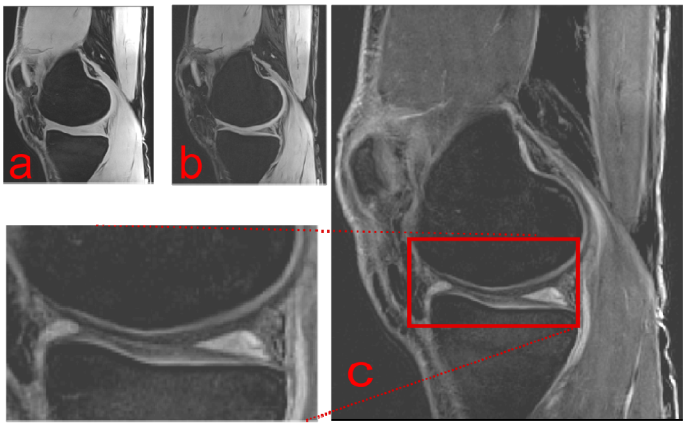

Figure 1: Knee scan at 3T: a. First echo (TE_{1eff}= 0.8 ms), b. Second echo (TE_2= 8.22 ms), c. Image difference

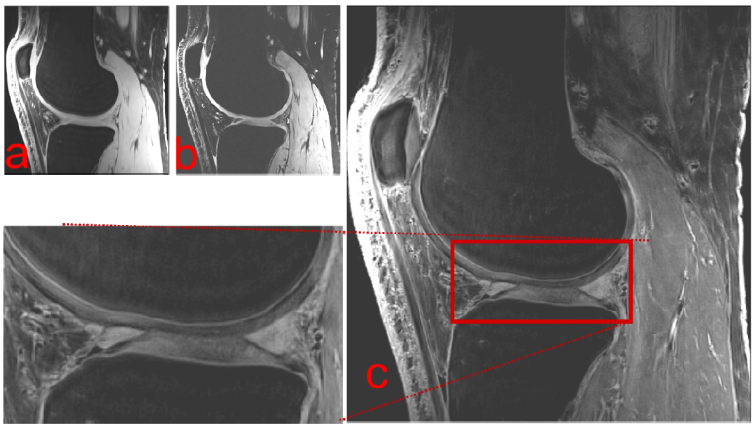

Figure 2: Knee scan at 7T: a. First echo (TE_{1eff}= 0.95 ms), b. Second echo (TE_2= 8.08 ms), c. Image difference

DISCUSSION and CONCLUSION: We showed that after optimization, a common 3D SPGR sequence can be used to achieve high resolution and high contrast-to-noise images for short T2 MSK components, such as menisci, tendons and ligaments. As compared to standard radial 3D UTE sequences, this approach benefits from the robustness of Cartesian sampling, provides an easy and flexible access to common acceleration techniques and offers the possibility for spatial spectral selection. Overall, SPGR sequences with optimized minimal TE show a great potential for broad clinical use within practically acceptable scan times.

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