Magnetic resonance imaging of tendons, ligaments and menisci by subtraction of two steady state free precession signals

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Purpose

Structure and composition of certain tissues result in short T_2 values and nearly lacking signal using conventional imaging sequences. Related effects can be observed especially in musculoskeletal tissues such as tendons, ligaments and menisci [1]. The MR signal from these tissues characteristically decays very rapidly (typical range $T_2 \approx$ 2-8 ms). In this work we aimed at improving the visualization of tendons, ligaments, and menisci by utilizing two *steady state free precession* (SSFP) signals S^+ and S^- which were simultaneously acquired in a constant readout gradient [2]. In contrast to the conventional *dual echo steady state* (DESS) sequences [3], which combine these signals into one by the calculation of the sum of squares of both echoes, in the presented SSFP sequence the final image is a subtraction of the two signals acquired. Furthermore, to enhance the contrast both echoes were acquired with a strong readout asymmetry.

Materials and Methods

Based on the theory of Bruder et al [2], the first echo S^+ allows for the formation of a FISP (*fast imaging steady precession*) image and the second echo S^- results in a PSIF (reversed FISP) image. The sequence is implemented in a manner that two echoes (S^+ and S^-) are acquired separately and reconstructed to the corresponding images (Fig. 1). To keep the echo time TE_1 especially short the echoes are acquired with a strong asymmetry of 75%. This particular sequence design allows for the visualization of tissue types with short T_2 relaxation time by plain subtracting the PSIF image from the FISP image. Asymmetric acquisition of two echoes provides a short echo time TE_1 for the first echo and a longer time $TE_2 = 2TR - TE_1$, leading to appropriate contrast-to-noise in the subtraction image. Furthermore, the application of non-selective rectangular RF excitation pulses (100 µs) allows for even shorter TE_1 of approximately 0.8 ms.

In-vivo measurements of healthy volunteers were performed on a 3 T whole-body MR scanner (Siemens Healthcare, Erlangen, Germany). An eight-channel transmit-receive knee coil was used for both RF transmission and signal detection. The three dimensional sequence was applied with the following parameters: readout asymmetry = 75 %, flip angle = 8°, TR = 3.5 ms, TE_1 = 0.8 ms, TE_2 = 5.0 ms, BW = 1565 Hz/pixel, voxel size = 1.5×1.5×1.5 mm^3, number of slices = 120, matrix size = 128×128, FoV = 192×192 mm^2, scan time = 55 sec.

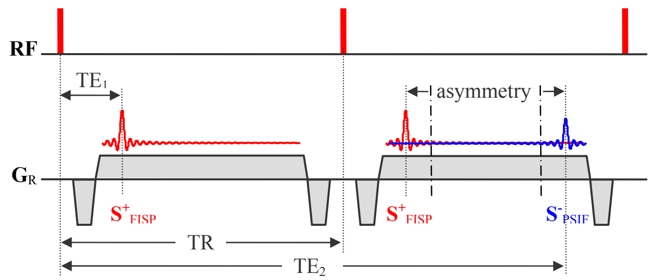

Fig. 1: Implemented pulse sequence with asymmetric acquisition of two steady state echoes S^+_{FISP} and S^-_{PSIF} (readout gradient only).

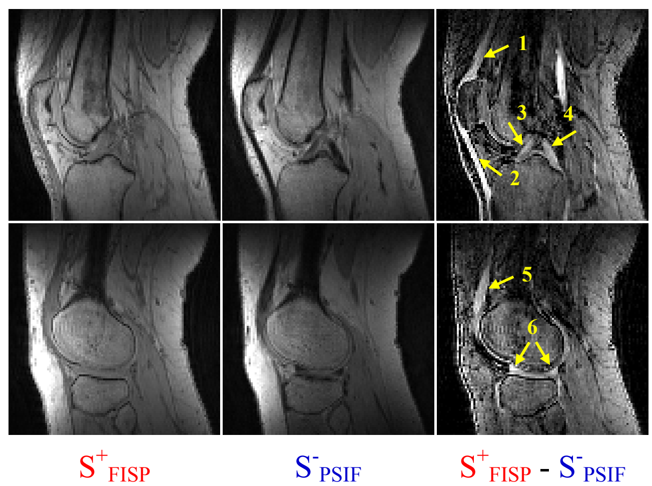

Fig. 2: Originally acquired S^+_{FISP} and S^-_{PSIF} images and calculated subtraction images (S^+_{FISP} - S^-_{PSIF}) of the knee joint of a healthy volunteer. Quadriceps (1) and patellar (2) tendon, anterior (3) and posterior (4) cruciate ligament, lateral retinaculum (5) and menisci (6) are seen as areas with “positive” signal intensity.

Results

By means of strong asymmetric echo acquisition and short non-selective excitation RF pulse an echo time of 0.8 ms was achieved. The proposed three dimensional SSFP sequence provided images with good delineation of tissues with short T_2 in the knee joint of healthy volunteers. In Fig. 2, original S^+_{FISP} and S^-_{PSIF} images and calculated subtraction images are presented. Quadriceps and patellar tendon, anterior and posterior cruciate ligament, retinacula and menisci could be visualized as hyperintense structures in the subtraction images.

Discussion

In musculoskeletal MR imaging tissues such as tendons, ligaments and menisci usually appear with low signal intensity, despite of their considerable proton density. In the presented work, we tried to delineate such tissues as areas with “positive” contrast using a modified steady state sequence.

Although recently introduced ultra-short echo (UTE) time sequences have the potential to visualize a variety of tissues with extremely fast signal decay in the µsec range [4], UTE-images show characteristic blurring that occur due to the radial data acquisition. Additionally, UTE sequences are not available in all institutions.

A drawback of the proposed SSFP approach is that the subtraction signal in muscle, fat and cartilage tissues is also relatively high because of the rather low S^- signal at small flip angles. The application of water selective excitation pulses is expected to yield improved image contrast. Alternatively, an accurate compensation of the in-phase/opposed-phase effects in both echoes should enhance the contrast in subtraction images. Self-weighted combination of both steady state echoes can also lead to higher signal-to-noise ratio [5]. Further developments are underway in order to improve the image contrast and to adapt this approach to the needs of clinical practice. In conclusion, the presented SSFP sequence is a promising technique which is worth being evaluated in clinical musculoskeletal MR imaging.

References

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