High-Resolution Cartilage Imaging with Wideband SSFP

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Introduction: Articular cartilage imaging demands high resolution and contrast between cartilage and surrounding tissues. Recently the application of SSFP on cartilage imaging has drawn people's attention with high SNR efficiency and excellent contrast between cartilage and synovial fluid [1]. However SSFP imaging suffers from its sensitivity to B_0 inhomogeneity, which increases with TR. So in order to prevent banding artifact, the readout length is constrained to keep TR short, resulting in a limited spatial resolution. Some SSFP-based sequences such as LCSSFP can remove banding artifact by acquiring several data sets with different spectral response, but requires prolonged scan time [2].

Wideband SSFP (wbSSFP) uses two alternating TRs to generate a pass band that has a bandwidth wider than 1/TR [3]. This method allows us to increase the readout duration without introducing severe image degradation. Thus we can obtain high-resolution images while image quality is preserved. In this work we compared wbSSFP with conventional SSFP in both simulation and cartilage images and obtained a high-contrast high-resolution cartilage image.

Method: Simulation of cartilage signal spectral responses from wbSSFP and conventional SSFP were performed in MATLAB. Cartilage T_1/T_2 = 1240/37 ms at 3T [4] were used in this simulation. Optimal flip angles were calculated by maximizing the cartilage to synovial fluid contrast with cartilage SNR efficiency not lower than 95% of its maximum [1].

In- vivo results were acquired in healthy volunteers using 2D axial slices covering a large section of patellar cartilage. Scans were performed on a GE Signa 3T scanner with a 5-inch surface coil. The slice thickness was 5 mm and the FOV was 15 × 15 cm. In wbSSFP a 1024 × 512 matrix was used, with TR / TRs = 10.8 / 2.8 ms for a total scan time = 35 s, flip angle = 31°. Two sets of conventional SSFP images were acquired, the first one with 512 × 512 matrix size and TR = 6.8 ms for a total scan time = 10 s, flip angle = 25°; the second one with 1024 × 512 matrix size and TR = 10.8 ms for a total scan time = 28 s, flip angle = 22°.

Results and Discussion: Fig.1 shows the simulated spectral responses of cartilage. wbSSFP with TR/TRs = 10.8/2.8 ms has a central bandwidth similar to conventional SSFP with TR = 6.8 ms, which is about 60% wider than SSFP with TR = 10.8 ms. The wbSSFP spectral response in Fig.1 is from the long TR period, and there is a significant signal level drop compared with conventional SSFP with TR = 6.8 ms. In this work we only used the long TR echo, trading signal for higher spatial resolution. SNR efficiency can still be retrieved by adding in short TR echo.

Images in Fig.2 show the in-vivo results from different sequences. Conventional SSFP sequence with TR = 6.8 ms enabled a readout matrix size of 512, which produced a 0.3 mm resolution along the readout direction. A wbSSFP sequence with TR/TRs = 10.8 / 2.8 ms had comparable off-resonance effect for cartilage and fluid, while holding a longer possible readout time. The resolution was of 0.15 × 0.3 × 5 mm in the wbSSFP scan. Conventional SSFP with TR = 10.8 ms attained the same spatial resolution with better SNR efficiency, however dark band started to appear at where different tissues are in contact.

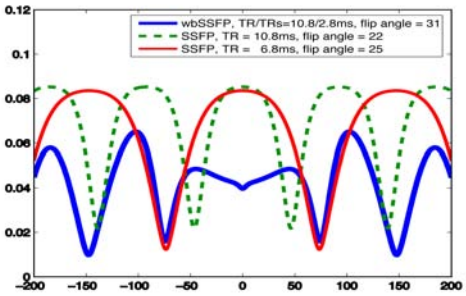


Figure.1 Signal profiles of wbSSFP with TR/TRs = 10.8/2.8ms (thick blue line), SSFP with TR = 6.8ms (thin red line) and with TR=10.8ms (dashed green line).

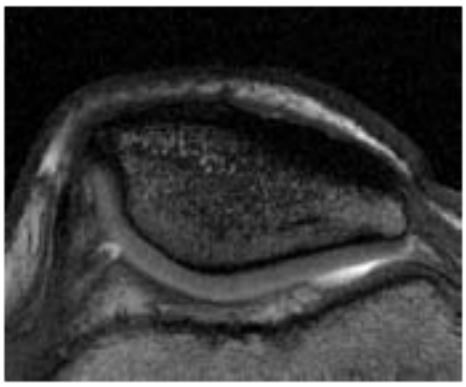
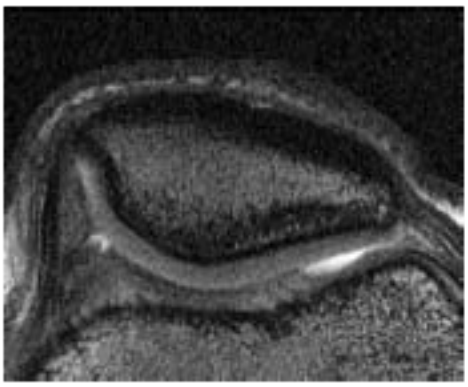
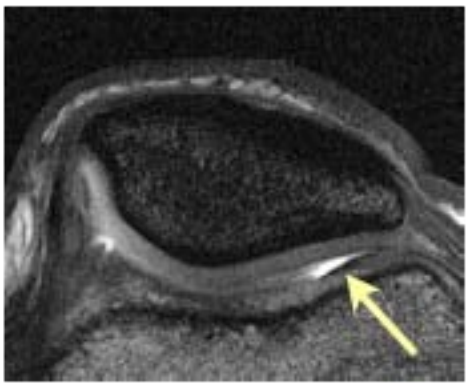


Figure.2 (a) SSFP image. TR = 6.8ms, resolution = 0.3 × 0.3 mm.



(b) wbSSFP image. TR/TRs = 10.8/2.8 ms, resolution = 0.15 × 0.3 mm.



(c) SSFP image. TR = 10.8ms, resolution = 0.15 × 0.3 mm. A banding artifact is indicated by the white arrow.

Conclusion: Wideband SSFP shows good contrast between cartilage and synovial fluid. An in-plane resolution of 0.15 × 0.3 mm was achieved by wbSSFP in a high-contrast cartilage image, which has less off-resonance artifact than conventional SSFP with the same resolution. This capability of obtaining high-resolution images makes wbSSFP a prospect for detecting degenerative changes in articular cartilage. The resolution in slice-select direction can still be improved by 3D imaging, and we also expect more accurate tissue discrimination by implementing fat-suppression techniques such as IDEAL [5].

References:

[1] Hargreaves et al., MRM 49:700-709(2003) [2] Vanasawala et al., MRM 43:82-90(2000) [3] Nayak et al., ISMRM 2005 p.2387 [4] Gold et al., AJR 183:343-351(2004) [5] Reeder et al., MRM 51:35-45(2004)