Musculoskeletal Imaging with PS-SSFP

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Introduction: Detailed articular cartilage evaluation with a 3D sequence such as spoiled gradient echo [1] is not routinely performed due to lengthy scan time. Thus, cartilage is typically evaluated with 2D FSE [2-3]. A novel fat-suppresed steady-state MRI technique, PS-SSFP, potentially offers fast 3D fat-suppressed morphologic assessment of joints with T2-like contrast in shorter scan time than FSE [4]. We hypothesize that compared with 2D FSE, PS-SSFP will have improved delineation of cartilage and similar sensitivity to joint pathology. Here we present initial results of comparison of PS-SSFP with proton density and T2-weighted FSE in patients with pathology.

Theory and Methods: PS-SSFP employs an SSFP sequence with TE = ½ TR. The signal spectral response is periodic [Fig. 1]. With decreasing TR, sensitivity to field inhomogeneity is less. With TR under 7 ms, and a center frequency set between that of fat and water, both fat and water resonance frequencies are in high signal regions of the spectral response. If TE is ½ TR, the signal phase profile is nearly constant aside from a 180 degree transition at the center frequency. Thus, fat has phase of $-\pi/2 + \phi$ and water has a phase of $\pi/2 + \phi$, where ϕ is a slowly varying phase independent of resonance frequency. Thus, water and fat signals are out of phase, as seen in Fig. 1. For practical implementation, complex images are first reconstructed using the standard Fourier transform algorithm. Then ϕ is estimated and removed, so the imaginary component of a voxel may be used to determine if the voxel signal is predominantly from fat or water. Voxels are thus binned to form two separate images.

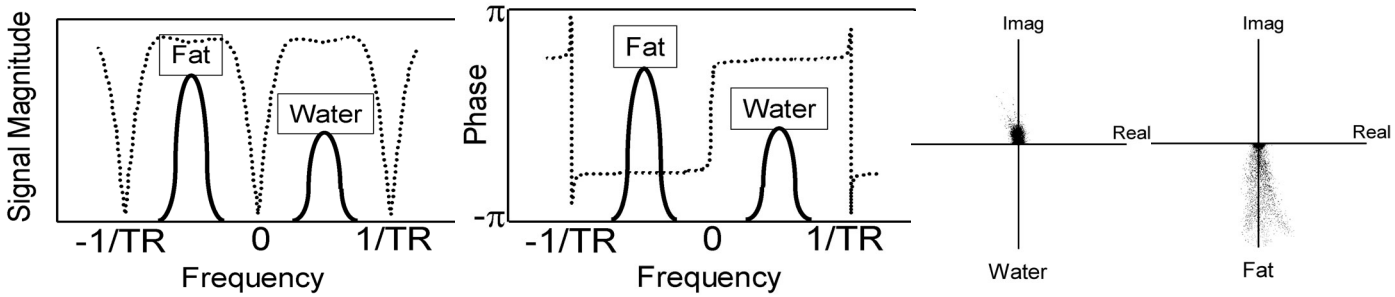

Fig 1. Left two graphs: Spectral response of SSFP signal magnitude and phase. Phase transition gives water voxels and fat voxels positive and negative imaginary components, respectively. Right two graphs: Scatter of complex voxel values in complex plane. Parsing by sign of imaginary component generates water and fat images.

To explore PS-SSFP performance, fourteen patients were scanned with SSFP at 1.5 T: TR 5.4 ms, flip angle 28 degrees, 16 cm FOV, matrix 256 x 256 for 0.625 mm in-plane resolution, 64 sagittal slices, 2 mm slice thickness, scan time 1:30. PS-SSFP reconstruction as described above was performed. Knees were also scanned in accordance with the sagittal sequences our institution's protocol: fat-suppressed T2-weighted FSE, with TR 5850 ms, TE 54, ETL 8, 16 cm FOV, 512 x 192 matrix, 3 mm slices, scan time ~3:13; proton density FSE, with TR 3325 ms, TE 15 ms, ETL 6, 16 cm FOV, 512 x 224 matrix, 3.5 mm slices, scan time ~4:18. Two radiologists reviewed the images, evaluating pathology as well as image quality, fat suppression, and cartilage conspicuity/uniformity/surface evaluation/thickness on a four point scale (1- nondiagnostic, 2- poor, 3- fair, 4- excellent).

Results: FSE and PS-SSFP demonstrated equivalent image quality and fat suppression (Fig. 2). PS-SSFP gave superior cartilage conspicuity, uniformity, surface delineation, and thickness demonstration (Wilcoxon signed rank test, $p < 0.02$ for each criterion). Eight patients demonstrated similar regions of bone marrow edema on both T2-weighted FSE images and on PS-SSFP images. Both methods demonstrated five cases of meniscal tear, and FSE demonstrated one additional meniscal tear. Each of two anterior cruciate ligament tears was revealed with PS-SSFP and FSE. Cartilage damage was shown by FSE and PS-SSFP in eight cases, by FSE only in one case, and by PS-SSFP only in one case.

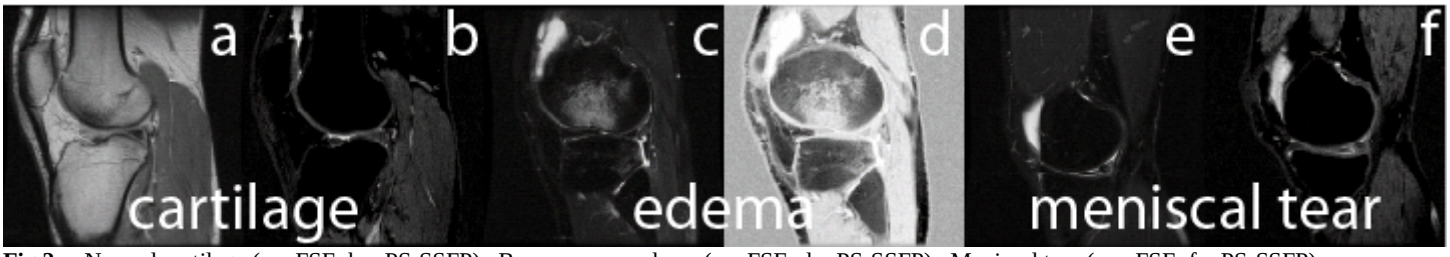

Fig 2. Normal cartilage (a – FSE, b – PS-SSFP). Bone marrow edema (c – FSE, d – PS-SSFP). Meniscal tear (e – FSE, f – PS-SSFP).

Discussion: A fast, efficient fat-water separated method of musculoskeletal imaging with excellent cartilage/synovial fluid contrast and fat suppression is presented. Preliminary results support equivalent image quality and fat suppression with PS-SSFP and FSE, and superior PS-SSFP delineation of cartilage. Limited experience suggests PS-SSFP and FSE depict bone marrow edema and meniscal injuries similarly. The method is faster than previously demonstrated methods, with volumetric evaluation of the knee in 90 seconds, roughly half the time of FSE.

References: **1.** Disler, DG, *AJR* 169:1117-1123, 1997. **2.** Escobedo, EM, *et. al. AJR* 167:1223-1227, 1996. **3.** Bredella, MA, *et. al. AJR* 172:1073-1080, 1999. **4.** Hargreaves, BA, *et. al. MRM* 50(1):210-3, 2003.