Spectroscopic Imaging using interleaved Projection sampling along the 3D Cartesion Phase and Slice encodings (SIPPS): application to articular cartilage

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INTRODUCTION

Reliable and uniform suppression of fat signal is essential for accurate diagnosis of many diseases. Conventional chemical shift selection suppression (CHESS) is efficient but may provide non-uniform fat suppression and reduced water signal in regions of field inhomogeneity (1-3). Short TI inversion Recovery (STIR) provides uniform fat suppression but also reduced water signal. The two-point Dixon technique offers a potential advantage in separating fat from water without inherent signal loss, but suffers from field inhomogeneity which creates phase errors and misclassification of water and fat (1). More refined multi-point Dixon methods account for B0 field inhomogeneity and provides more reliable fat water separation (2, 3). Another way to separate fat and water is spectroscopic imaging, which generates images at a series of resonance frequency offsets, therefore immune to B0 field inhomogeneities and susceptibility effects. But conventional spectroscopic imaging techniques provide poor spatial resolution and require a long scan time, limiting their application in fat and water imaging. Here we report a novel approach for fat water separation termed Spectroscopic Imaging using interleaved Projection sampling along the 3D Cartesian Phase and Slice encodings (SIPPS), which provides high spatial resolution fat and water images in clinically acceptable scan times.

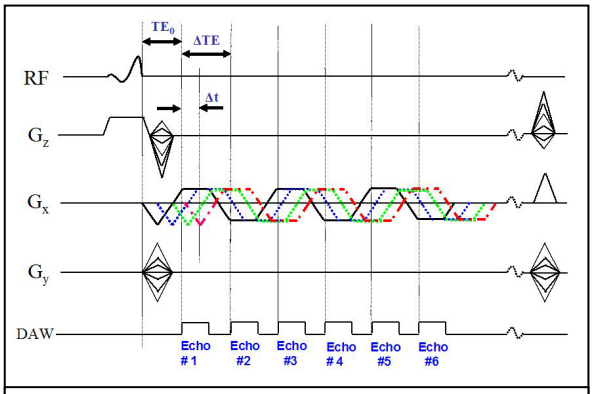

Fig 1 *SIPPS sequence combines multi-echo (echo space ΔTE) gradient echo 3D Cartesian acquisition with variable TE delay (Δt) to detect signal decay and spectroscopic information.*

MATERIALS AND METHODS

The SIPPS technique is based on a clinical 3D spoiled gradient echo sequence which combines multi-echo gradient echo (up to 8 echoes) acquisition with variable TE delay, as shown in Figure 1. The Cartesian k-space is partitioned into multiple interleaved sets of half projections in the ky-kz plane (Figure 2). Each interleave has a different TE delay with an odd number of half projections (typically 59 to 95) creating an undersampled asymmetric coverage of the ky-kz space with reduced artifact in a shorter scan time (4). The central phase/slice encodings (such as 1000) are always sampled for each interleave, regardless of the pre-defined radial trajectories for improved artifact control. High frequency phase and slice encoding data are shared among the neighbor interleaves for further reduction of the undersampling artifact. Furthermore, the residual streak artifact can be controlled by sampling the multiple interleaves in a way such that the streaks oscillate periodically in the time domain images. For example, for 9 interleaved projection sets, a sampling order of 1, 4, 7, 2, 5, 8, 3, 6 and 9 will create streaks oscillating every three echo images. Fourier transformation of the time-domain images will shift the periodic streaks to high spectral frequencies, leaving streak artifact free images near the water and fat resonance peaks. A ball phantom was first subject to SIPPS imaging to investigate its efficiency in streak artifact reduction. The SIPPS technique was then applied to image knee articular cartilage in five normal human volunteers. Typical acquisition parameters included: FOV of 16 cm, 40 to 72 slices, 1.5 to 2 mm slice thickness, readout = 512, TR = 10 to 25 ms, 1 to8 echoes, flip angle = 30°, bandwidth = ±125 kHz, 9 interleaves, TE delay of 300 to 500 μs, total scan time = 5 to 12 minutes.

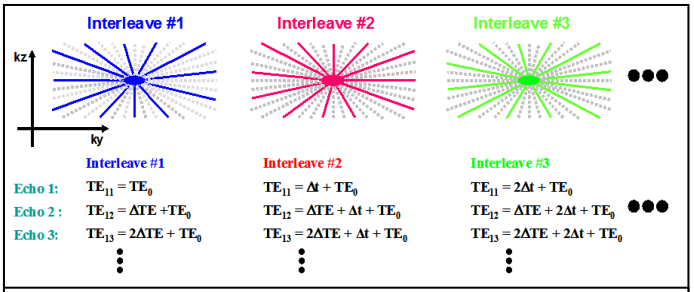

Fig 2 *SIPPS data acquisition scheme: k-space is partitioned into multiple half projections in the ky-kz plane which are interleaved into multiple groups with each group sparsely but uniformly covering the ky-kz plane. The multi-echo data is progressively delayed by Δt for each interleave.*

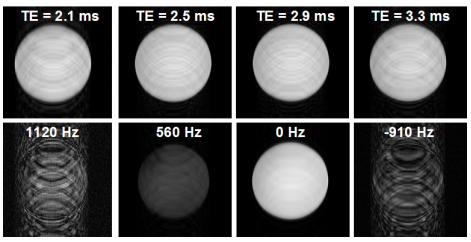

Fig 3 *SIPPS imaging of a ball phantom in the time domain at variable TEs (upper row) and spectral domain at different resonance frequencies (lower row). The periodical undersampling artifact in time domain is shifted to high spectral frequencies, leaving artifact free images at the water peak (0Hz).*

RESULTS AND DISCUSSION

Figure 3 shows the ball phantom study, where the residual undersampling artifact appears periodically in the time domain and is shifted to high spectral frequencies in the spectral domain, leaving artifact free water images. Figure 4 shows selected fat and water images of the knee of a 30 year old volunteer. Excellent fat water separation is demonstrated with a large matrix size of 512×512×64 and high spatial resolution of 0.31×0.31×2.0 mm^3 with a total scan time of 11 minutes. The multi-echo images (up to 8×9 = 72 echoes) can also be used to generate 3D T2* map, which is another advantage of the SIPPS technique.

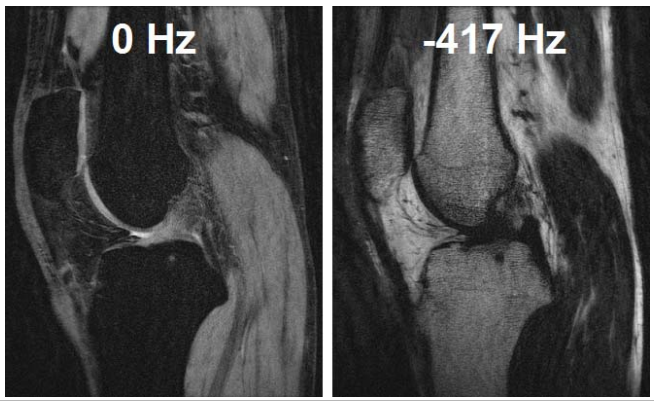

Fig 4 *Selected 3D spectroscopic images at the water peak (left) and near the fat peak (right) show excellent fat/water separation with minimal undersampling artifact which is shifted to high spectral frequencies. The 3D volumetric data has a high spatial resolution (0.31×0.31×2.0 mm^3) and moderate spectral resolution (70 Hz) under a total scan time of 11 min.*

CONCLUSIONS

SIPPS provides accurate and robust 3D fat and water images with high spatial resolution and minimal undersampling artifact in clinically acceptable scan times.

REFERENCES

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