Compressive Chemical-Shift-Based Rapid Fat/Water Imaging

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Introduction:
Chemical-shift based fat and water separation techniques [1,2] are very common in practice and are effective in revealing important clinical information. They require imaging at multiple echo times, which often results in additional scan time. As compressed sensing (CS) [3-5] acceleration techniques become more available, it is necessary to be able to separate between fat and water in the CS framework to provide robust, high quality, fast acquisition, fat/water separated clinical images. In this work we explore the feasibility of sparsity based fat/water accelerated imaging by reconstructing chemical-shift spectra from randomly undersampled phase encodes acquired at random echo-times with CS.

Theory: Successful CS requires: compressibility of the underlying signal, incoherent sampling and a non-linear sparsity enforcing reconstruction. It has been demonstrated that medical images in general are compressible/sparse to some degree. This has been used to accelerate scans using CS [5]. The majority of voxels in clinical images mostly contain either water or lipid signal (and some contain both). Therefore their spectra are also sparse. The sparsity of spectra has been previously used to accelerate 13C hyperpolarized chemical-shift imaging [6]. The spectral sparsity can also be used to separate the water and lipid signals in clinical imaging.

Methods:
We propose to acquire phase-encodes at random (with variable density). In addition, each phase-encode’s echo-time is delayed differently. The delay is chosen at random out of several possibilities (that meet the required spectral resolution and spectral bandwidth). The proposed sampling scheme is demonstrated in Fig. 1. In effect, the full 3D chemical-shift k-space grid is randomly undersampled.

The entire chemical-shift multi-dimensional image is then reconstructed (using SparseMRI [5]) from the undersampled data by enforcing sparsity of both the spectrum and sparsity of spatial finite differences (Total Variation), or spatial wavelet transform.

Results:
To demonstrate the feasibility of this approach we acquired fully sampled data sets of a volunteer’s knee at six different echo times (TE=7,9,11,13,15,17ms) using a 3D SPGR sequence implemented on a 1.5 GE Signa Excite scanner. The following parameters were used: TR=30ms, Flip 30, matrix=160x128x52, FOV=14cm. The data was retrospectively undersampled using the scheme described in Fig. 1. The remaining dataset was only 1.7 times larger than that of a single echo fully sampled image. The 3D images and their spectra were reconstructed using the SparseMRI package [5] enforcing sparsity of the spectra and spatial TV penalty. Lipid and water images were then constructed using sum-of-squares (SOS) of the lipid and water bands [8]. The results shown in Fig. 2 demonstrate good quality reconstruction of the lipid and water images compared to the images reconstructed from the full dataset.

Conclusions:
We demonstrated the feasibility of Fat/Water separation by exploiting the sparsity of the images and the water-fat spectrum. We achieve good quality separation with only 70% more samples than a single image (IDEAL [2] or Dixon-type [1] method require 200% more). Since the spectrum for each voxel is reconstructed, the method automatically provides the fat/water content and in addition off-resonance maps can be computed.