

Water Fat Separation with Multiple-Acquisition bSSFP

Michael Anthony Mendoza¹, Raul Villalpando¹, Danny Park¹, Daniel Gardner¹, Kevin Perkins¹, and Neal Bangerter¹
¹Electrical Engineering, Brigham Young University, Provo, Utah, United States

Introduction: Balanced steady-state free precession (bSSFP) MRI is a technique capable of producing images with high signal-to-noise ratio (SNR) in a short imaging time but suffers from bands of signal loss due to magnetic field inhomogeneity and susceptibility variations. These bands of signal loss degrade image quality. Several methods have been developed to remove these banding artifacts. The simplest methods combine images across multiple bSSFP image acquisitions. Reliable and uniform water fat separation, which can be used to improve medical diagnosis, is also a challenging problem. In many applications the water component is the primary signal of interest, while the fat component represents a signal that can obscure the underlying pathology or other features of interest. In other applications the fat signal is the signal of interest.¹⁻⁴

This work was motivated by the need for robust water fat separation and band reduction in the presence of field inhomogeneity when using bSSFP. In this work, we present a novel technique that combines the advantages of bSSFP with Dixon reconstruction in order to produce robust water fat decomposition with high SNR in a short imaging time, while simultaneously reducing banding artifacts that traditionally degrade image quality.

Theory: At large flip angles, the bSSFP signal level, as a function of off-resonance frequency, forms a sinusoidal-like spectral profile. This spectral profile can be arbitrarily shifted in frequency by increasing the phase of the RF pulse by a constant value, $\Delta\phi$, from excitation to excitation.¹ When four phase-cycled bSSFP images are acquired with $\Delta\phi = 0^\circ, 90^\circ, 180^\circ$, and 270° , they generate four evenly distributed signals along a bSSFP spectrum (Figure 1). On a voxel-by-voxel basis, the three greatest magnitude signals from these images, which are located in the pass band region, are combined to generate a more homogenous signal with reduced banding artifacts.

The choice of echo time (TE) effects the relative phase between water and fat components due to the chemical shift. For a given difference in resonance frequency between water and fat (CS_f), the time between successive images (Δt) is selected to generate “in-phase” images (images with a 0, or 2π phase difference) and “out-of-phase” images (images with a π phase difference). A time difference between images equal to odd integer multiples of $1 / (2 * CS_f)$ is used to generate “in-phase” images, while a time difference equal to even integer multiples of $1 / (2 * CS_f)$ is utilized to produce “out-of-phase” images. Linear combinations of these images, according to Dixon reconstruction, can be used to produce separate water and fat images.^{2,3}

These two ideas form the basis for Water Fat Separation with Multiple-Acquisition bSSFP. This algorithm utilizes four phased-cycled bSSFP acquisitions at specific echo times to generate “in-phase” and “out-of-phase” images. Linear combinations of the highest magnitude signals from these images are used to produce separate water and fat images.

Methods: Four phased cycled bSSFP images of an oil/water phantom were generated by both a bSSFP simulation and by a 3T Siemens scanner. The common bSSFP parameters for the all images were: flip angle=90 degrees and TR=10ms. The respective parameters for each of the four phase-cycled images (Figure 2a-d) were: $\Delta\phi = 0^\circ, 90^\circ, 180^\circ, 270^\circ$ and TE = 3.25 ms, 4.42 ms, 5.58 ms and 6.75 ms. Images were reconstructed on a voxel-by-voxel basis.

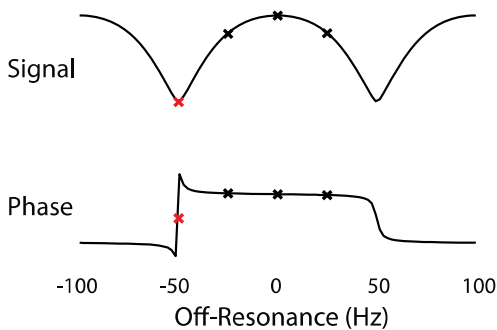


Figure 2: The bSSFP signal as a function of off-resonance frequency at large tip angle. Selecting four evenly distributed points along one cycle of a bSSFP spectrum places only point at a signal null.

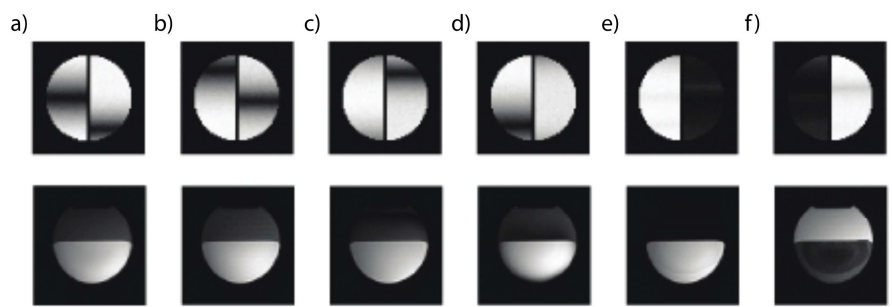


Figure 1: Simulated oil/water phantom (top) and real oil/water experiments (bottom) demonstrating Water Fat Separation with Multiple-Acquisition bSSFP. (a-d) Four-cycled images with $\Delta\phi = 0^\circ, 90^\circ, 180^\circ, 270^\circ$. (d) Estimated water image (e) Estimated fat image.

Results and Discussion: The simulated and acquired results for an oil/water phantom are shown in Figure 2. The first four images in each series are the generated phase-cycled images, while the last two are the water and fat images respectively. Note reduction of the fat component in the water image and the reduction of the water component in the fat image. These results are promising, in reasonable agreement with theory and show that the algorithm is capable of water fat separation in the presence of SSFP banding artifacts due to field inhomogeneity. While, capable of water fat separation, the reconstruction method is not yet robust in the presence of strong field inhomogeneities that produce a large number of banding artifacts in bSSFP. Further work will explore methods for eliminating these errors.

References:

- [1] Quist et al., Magnetic Resonance in Medicine, 2012
- [2] Dixon, Journal of Radiology, 1984.

- [3] Glover and Schneider, Journal of Magnetic Resonance in Medicine, 1991.
- [4] Hargreaves et al., Magnetic Resonance Imaging, 2006