Simultaneous Fat Suppression and Band Reduction with Large-Angle Multiple-Acquisition bSSFP

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INTRODUCTION: Balanced steady-state free precession (bSSFP) is a rapid and SNR-efficient imaging method, but suffers from characteristic bands of signal loss in regions of large field inhomogeneity. Several methods have been developed to eliminate or reduce the severity of these banding artifacts, typically involving the acquisition of multiple bSSFP data sets (and the accompanying increase in scan time) [1-4]. Fat suppression with bSSFP is also challenging; most existing methods require an additional increase in scan time, and some are incompatible with bSSFP band-reduction techniques [5-7].

This work was motivated by the need for both robust fat suppression and band reduction in the presence of field inhomogeneity when using bSSFP for flow-independent peripheral angiography [8]. The large flip angles used in this application to improve vessel conspicuity and contrast lead to SAR considerations, longer TR, and increased severity of banding artifacts. In this work, we present a novel method that simultaneously suppresses fat and reduces bSSFP banding artifact with the acquisition of only two phase-cycled bSSFP data sets and a field map.

THEORY: As flip angle is increased, the bSSFP signal level as a function off-resonance frequency begins to approximate a sinusoid for many biological tissues (Figure 1a). (Note that this approximation requires TE = TR/2.) This spectral profile can be arbitrarily shifted in frequency by incrementing the phase of the RF pulse by some $\Delta\phi$ from excitation to excitation [1]. When two large-flip-angle (~70° or greater) bSSFP acquisitions are performed with $\Delta\phi = 0°$ and $\Delta\phi = 180°$, the spectral profiles of the acquisitions approximate a sine and cosine, respectively. A dataset with spectral profile shifted by an arbitrary Δf can then be synthesized from the two acquisitions, using the relationship $\sin(f + \Delta f) = \cos(\Delta f)\sin(f) + \sin(\Delta f)\cos(f)$, as shown in Figure 1b.

Choice of TR such that $TR = n / (2{*}CS_f)$, where n = 1, 3, 5, … and CS_f is the absolute chemical shift of fat relative to water (in Hz), will place fat in a signal null whenever water is at a signal maximum (Figure 1b). If the appropriate frequency shift Δf needed to place water on a signal maximum is then identified on a voxel-by-voxel basis, a fat-suppressed image without banding can theoretically be formed from the two phase-cycled acquisitions. This forms the basis for our large-angle multiple-acquisition (LAMA) bSSFP technique. The required frequency shifts can be determined through acquisition of a field map, although preliminary work has suggested that an intelligent search of voxel intensities over a range of Δf values may yield better results and eliminate the need for field map acquisition. In this case, a region-growing algorithm could be used to distinguish between fat and water voxels, and the appropriate minimum-valued (fat) or maximum-valued (water) selection made on a voxel-by-voxel basis across Δf values.

METHOD: Two phase-cycled bSSFP images and a field map were acquired of an oil/water phantom (Figure 2a-c) and the lower leg of a normal volunteer (Figure 2d-f) on a GE 1.5T scanner. bSSFP parameters were: flip angle = 90° (phantom) and 70° (volunteer), TR/TE = 6.6/3.3 ms, and phase cycling of $\Delta\phi = 0°$ and 180°. Images were then reconstructed on a voxel-by-voxel basis, summing voxels from each of the phase-cycled images with a weighting (and thus a spectral shift) determined from the field map.

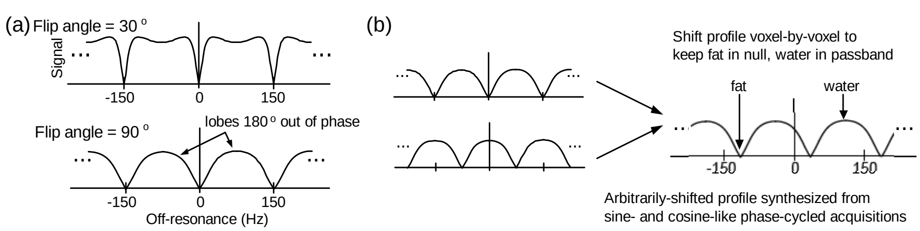

Figure 1: (a) For flip angles close to 90°, the bSSFP signal as a function of off-resonance begins to approximate a sinusoid for many tissues. (b) Two large-angle phase-cycled acquisitions can be combined to synthesize an arbitrarily-shifted bSSFP profile. Appropriate choice of TR then allows fat to be placed in the signal null on a voxel-by-voxel basis.

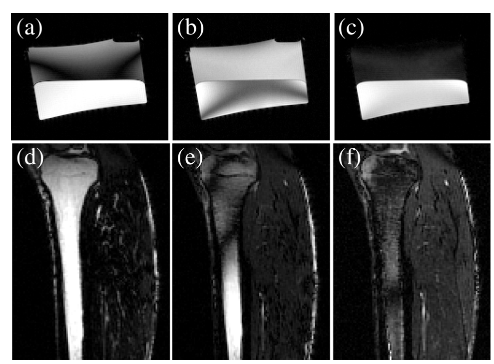

Figure 2: Oil/water phantom (top) and lower-leg (bottom) experiments demonstrating LAMA bSSFP. (a,d) bSSFP acquisition with $\Delta\Phi = 0°$, (b,e) bSSFP acquisition with $\Delta\Phi = 180°$, and (c,f) LAMA bSSFP. Fat is well suppressed by the LAMA technique, and banding greatly reduced.

RESULTS AND DISCUSSION: Results are shown in Figure 2. While this is a simple demonstration-of-concept study, the results are promising and in reasonable agreement with theory. However, the reconstruction method as tested is not yet robust, and is sensitive to constant frequency offsets in the field map. Further work will explore methods for eliminating field map acquisition (as mentioned above) and applications at 3T.

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