Utilization of a bSSFP Signal Model for Improved Fat/Water Decomposition in bSSFP Breast Imaging

Leah C Henze Bancroft[1], Diego Hernando[2], Kevin M Johnson[3], Frederick Kelcz[2], Roberta Strigel[2], and Walter F Block[1,3]
[1]Biomedical Engineering, University of Wisconsin - Madison, Madison, WI, United States, [2]Radiology, University of Wisconsin - Madison, Madison, WI, United States, [3]Medical Physics, University of Wisconsin - Madison, Madison, WI, United States

Introduction: Proper modeling of fat with a multipeak spectrum significantly improves the decomposition of fat and water using IDEAL [1]. Normally IDEAL utilizes models where the fat peaks accrue phase linearly from a reference point (from the RF pulse for Gradient Echo and t = TE for Spin Echo). Presented here are previously uncharacterized changes to this model due to bulk phase changes and amplitude modulations that occur with the use of a bSSFP sequence as well as a method for incorporating this model into a fat/water decomposition algorithm.

Theory and Methods Amplitude and nonlinear phase modulation within fat (shown in green in Fig 1B and C) are due to the constructive and destructive interference between the multiple fat peaks shown in Fig 1A. bSSFP is often conceptualized as refocusing and peaking at TE=TR/2 but the actual amplitude modulation within the TR is more complex (red line, Fig 1 B, C). Bulk phase offsets between frequency components in different pass bands as well as relative amplitude scaling due to the bSSFP magnitude response alter the signal. In the presence of B0 inhomogeneity, the fat spectral peaks are shifted within the bSSFP pass bands, altering the bulk phase offset and relative amplitude scaling of the different components (Fig 1 D), which can significantly alter the magnitude and phase response (Fig 1 E, F). When these differences from the multipeak fat model are not accounted for in IDEAL for a bSSFP scan, the signal modulations will manifest themselves as leakage in the water channel as shown in Fig 2A.

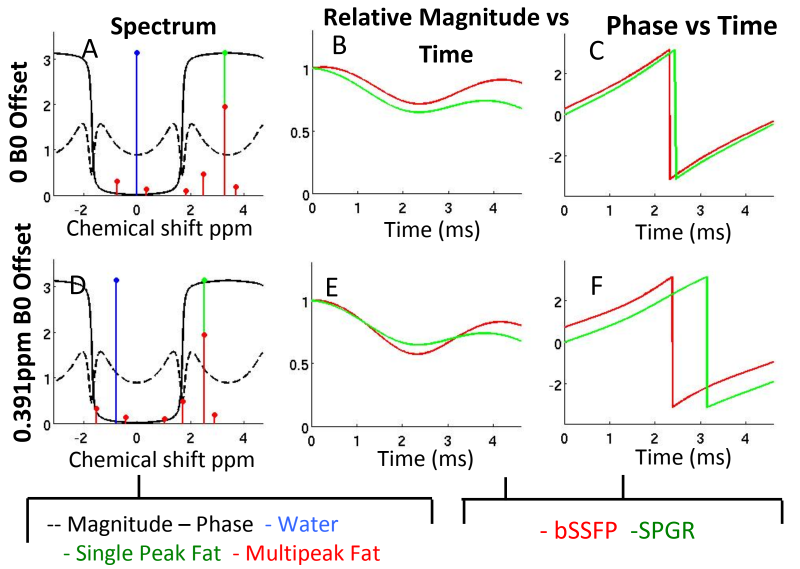

Figure 1: The spectrum of fat and water along with the bSSFP magnitude and phase response for B0 offsets (A) of 0 and (B) 0.391 ppm. The TR was chosen to place the water and main fat peak centered in different pass bands. The bulk phase modulation (π phase shift between components in different pass bands for TE=TR/2) and amplitude modulation caused by the bSSFP magnitude response cause the output signal magnitude (B and E) and phase (C and F) responses (red line) to differ greatly from that of SPGR (green line).

To overcome this problem, we incorporated a bSSFP signal model into the fat / water decomposition process. A regularized technique for B0 fielmap estimation including smoothness constraints and solved using a graph-cut iterative algorithm [2] was applied to the data to calculate the B0 fieldmap. The bSSFP signal model is then recalculated for each voxel given the local B0 offset and a psudo inverse decomposition is performed to determine the fat and water components. We have recently combined this method with our 3D Radial bSSFP VIPR sequence, which utilizes a two pass data collection scheme with delays to collect 4 echo times [3]. This allows for the generation of images with high 0.6 mm spatial resolution but sill keeps the TR short (4.6 ms) to avoid banding artifacts. Due to uncharacterized magnitude instabilities in our pulse sequence, we currently fit echo data only to the altered bSSFP phase model. Three healthy breast volunteers were imaged using this method (Fig 2).

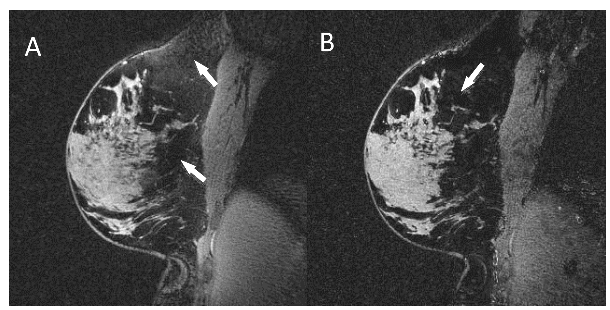

Figure 2: Images reconstructed using a multipeak (A) and multipeak bSSFP (B) signal model. Variable fat suppression can be seen in A and nearly complete fat suppression in B as indicated by the white arrows.

Results / Discussion Properly Incorporating the bSSFP signal model greatly improved the consistency of fat decomposition as demonstrated in Figure 2B. The variable fat suppression in Figure 2A is likely a result of the SPGR multipeak signal model and bSSFP signal being well aligned for the B0 offset in some regions while in other regions the B0 offset leads to large differences between the SPGR model and the actual bSSFP signal. The current implementation can be improved by resolving the magnitude instabilities in the pulse sequence. The magnitude varies greatly across B0 offset (Fig 1B,E) so incorporating this data into the decomposition would likely improve the fit.

Conclusion The amount of fat signal leaking into the water images was greatly reduced when a bSSFP signal model was incorporated into a fat/water decomposition algorithm. Further improvements to the pulse sequence will improve the robustness of the method.

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References [1] Yu H, *et al*. MRM 60(5):1122-1134 (2008) [2] Hernando D, et al. MRM 63:79-90 (2010) [3] Moran CJ, *et al*, MRM *in press*.