Multiple Acqusition Phase-Sensitive SSFP Water-Fat Separation

B. A. Hargreaves[1], N. K. Bangerter[1], S. S. Vasanawala[2], A. Shimakawa[3], J. H. Brittain[3], D. G. Nishimura[1]

[1]Electrical Engineering, Stanford University, Stanford, CA, United States, [2]Radiology, Stanford University, Stanford, CA, United States, [3]Applied Science Lab - West, General Electric Healthcare, Menlo Park, CA, United States

Introduction: Although balanced SSFP imaging yields high SNR in short scan times, it suffers from bright fat signal and high sensitivity to off-resonance that results in null (dark) signal bands [1]. Numerous techniques to reduce the effects of the null signals [2,3] and bright fat [3-6] have been proposed. We present a technique that simultaneously addresses both effects. This technique enables balanced SSFP for applications such as high-resolution imaging and high-field imaging, where the minimum repetition time (*TR)* may be too long to prevent null signal bands.

Theory: In balanced SSFP with *TR*=2*TE*, the signal is refocused to a spin echo, with a sign that alternates with frequency spacing 1/*TR*. Placing water and fat in signal bands with opposite sign allows separation using the sign [6]. Figure 1 shows (with *TR*=2*TE*=4.6 ms) that the complex addition of two images with RF phase increasing by 180° (dashed line) and 0° (dotted line) yields a signal with nearly linear phase, fairly smooth magnitude, and water and fat 180° out of phase at 1.5 T regardless of field variation. This addition is intuitively approximated by the sum in the complex exponential, $e^{i\omega} = \cos(\omega)+i\sin(\omega)$.

Assuming a slowly-varying field, the resulting phase can be removed using phase-correction methods [6,7] as follows: Each complex voxel is squared to remove the water/fat 180° ambiguity. The phase angle is fitted, then divided by two. Finally, the phase is flipped by 180° as necessary, to constrain it to vary slowly in space. This phase is removed, leaving a predominantly real-valued signal with a sign change between water and fat, allowing their separation.

Methods and Results: At 3.0 T, we imaged the lower leg of two normal volunteers, using *TR*=2*TE*=11.9 ms, thus placing water and fat 5 signal bands apart. Other parameters were a 50° flip angle, 512x240x96 matrix, 0.5x0.7x1.0 mm^3 resolution, and two (0° and 180° RF phase increment) acquisitions for a total scan time of 9:10. Figure 2 shows the 0° and 180° images, and the reconstruction process. The magnitude and phase variations from null signal bands (shown by arrows) are removed by the complex image sum [8] and phase correction, permitting accurate separation of water and fat.

At 1.5 T, we imaged the feet of three normal volunteers with the goal of a maximum-intensity projection (MIP) angiographic image. Scan parameters were *TR*=2*TE*=4.6 ms, 60° flip angle, 1.0x1.0x1.0 mm^3 resolution, and two (0° and 180°) acquisitions (5:11 total scan time). Figure 3 shows that the complex sum enables the correct MIP while the original phase-sensitive SSFP method [6] fails due to field variations.

Discussion: We have shown that water-fat separation is feasible using multiple phase-cycled balanced SSFP acquisitions. Although the method is limited by partial-volume effects, and future work is necessary to validate robustness, this technique represents a rapid, SNR-efficient option for water-fat separated balanced SSFP when the *TR* is too long to prevent null signal bands. This method may enable balanced SSFP acquisitions for applications such as high-resolution, high field imaging, where spatial resolution and patient heating force a minimum *TR* that prohibits the use of standard SSFP techniques.

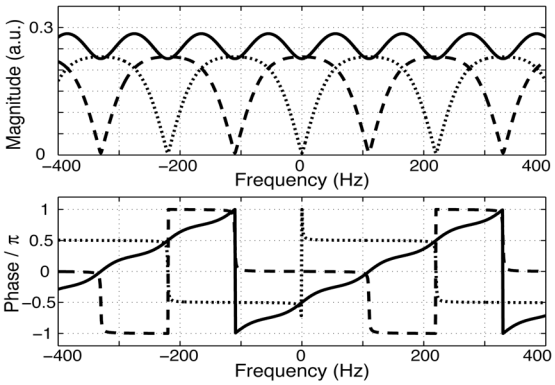

Figure 1. *Magnitude (top) and phase (bottom) of balanced SSFP acquisitions with RF phase increment of 0° (dotted line) and 180° (dashed line), and of the complex sum signal (solid line).*

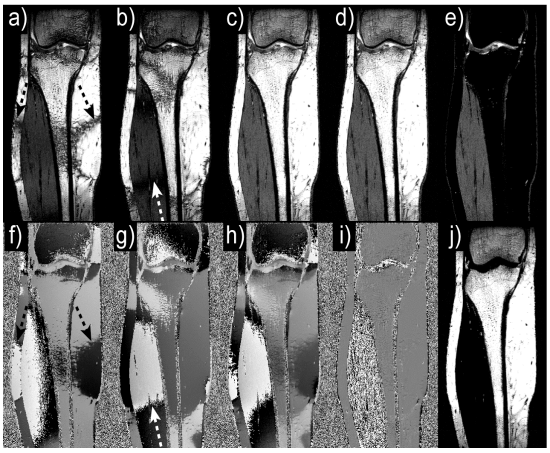

Figure 2. *Magnitude (a,b) and phase (f,g) for 0° and 180° images at 3T with 11.9 ms TR. Magnitude (c,d) and phase (h,i) of complex sum of images before and after phase correction respectively. Magnitude images of water (e) and fat (j) show correct separation.*

Figure 3. *MIP images of a normal foot at 1.5T, following phase-sensitive water-fat separation applied to source images (left, center) and to the sum (right). Incorrect separation due to field variations prevents separation of the subcutaneous fat (left, center). The proposed technique gives the correct separation and a useable MIP image (right).*

References:

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