Dixon bSSFP in the Presence of B_o Inhomogeneities

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Introduction: The two-point, fat/water-separation Dixon method for balanced steady-state free precession (bSSFP) introduced by Huang *et al.*[1] shows great promise for non contrast-enhanced MR angiography[2]. Here, we investigate its limitations in the presence of B_o inhomogeneities (*i.e.*, from magnet non-uniformity, susceptibility, *etc.*), and for pixels containing a mixture of fat and water. From the analysis, we propose acquiring/using a B_o inhomogeneity map to better suppress fat and produce more robust water-only images.

Methods: All simulations were done in Matlab (version 7.4; The MathWorks, Natick, MA), with the theoretical, noise-free signals synthesized using the general SSFP equations from Haacke *et al.*[3] We used typical 3.0 tesla values for the tissue parameters M_o, T_1, T_2, and chemical shift (CS) of fat and water, namely M_o: 0.9/1.0, T_1: 300/1100 ms, T_2: 60/50 ms, and CS: -440/0 Hz, respectively. The cycle time, τ_{cyc}, of fat with respect to water is ~2.27 ms. The Huang-Dixon method requires (i) TR to be an odd half-multiple of τ_{cyc}, (ii) TE = ½TR, and (iii) two acquisitions with different centre frequency (CF) offsets. The water-only signal is calculated from the complex addition of the two scans. Simulations shown here used TR/TE: 3.4/1.7 ms, a 25° flip angle, and $\gamma\Delta B_o$ within ±300 Hz.

Results: SSFP techniques are known to exhibit periodicity with respect to off-resonance frequency, whereby the signal "bandwidth" BW_{ssfp} is 1/TR (*i.e.*, ~294 Hz herein). Consequently, water that is off-resonant by $\pm$½BW_{ssfp} yields little signal and produces the familiar dark bands. By applying a centre frequency offset of say δf, BW_{ssfp} is unchanged but the dark bands shift commensurately (*e.g.*, to $\delta f \pm$ ½BW_{ssfp} for water). Below are two Huang-Dixon outcomes (with CF offsets of ±110 and ±74 Hz, top row) for pixels containing only water or only fat. At first glance, the ±110 Hz results seem more desirable, but the water signal is noticeably apodized. By comparison, the ±74 Hz (*i.e.*, ±¼BW_{ssfp}) offsets show a more symmetric/periodic behavior, and the complex subtraction (not shown) is its complement. Now, for an equal muscle-to-fat mixture, admittedly the worst-case scenario, the outcomes (bottom row) are striking: periodicity is still evident, the complementary nature of the complex add/subtract signals is seen only for the ±74 Hz centre frequency offsets (±¼BW_{ssfp}), and the desired water signal is more severely modulated as compared to the no-mixture results.

Conclusion: Increasing the B_o uniformity is clearly of paramount importance for the Huang-Dixon method. However, the diagrams below show that by using CF offsets of ±¼BW_{ssfp}, the complex add/subtract results are complementary. This suggests that if one acquires a B_o inhomogeneity map (which may be of lower resolution), and apples (i) complex *summation* for pixels within the frequency ranges $\gamma\Delta B_o = \{ (n+¼)BW_{ssfp} \text{ to } (n-¼)BW_{ssfp} \}$, with n an integer, and (ii) complex *subtraction* otherwise, one should ideally obtain an improved, fat-suppressed, mostly-water bSSFP image. More specifically, (a) for mostly-water pixels (upwards of ~80%), the banding artifacts would be significantly reduced, (b) mostly-fat pixels would be suppressed in the water-only image, regardless of B_o inhomogeneity, and (c) pixels that contain comparable amounts of fat and water *might* show band artifacts, but only for those pixels that are off-resonant near odd multiples of ±¼BW_{ssfp}.

References: [1]TY Huang, *et al*. Magn Reson Med 2004, 51:243. [2]R Stafford, *et al*. Magn Reson Med 2008, 59:430. [3]EM Haacke, *et al*. "Magnetic resonance imaging: Physical principles and sequence design", John Wiley and Sons, New York, 1999, Chapter 18.

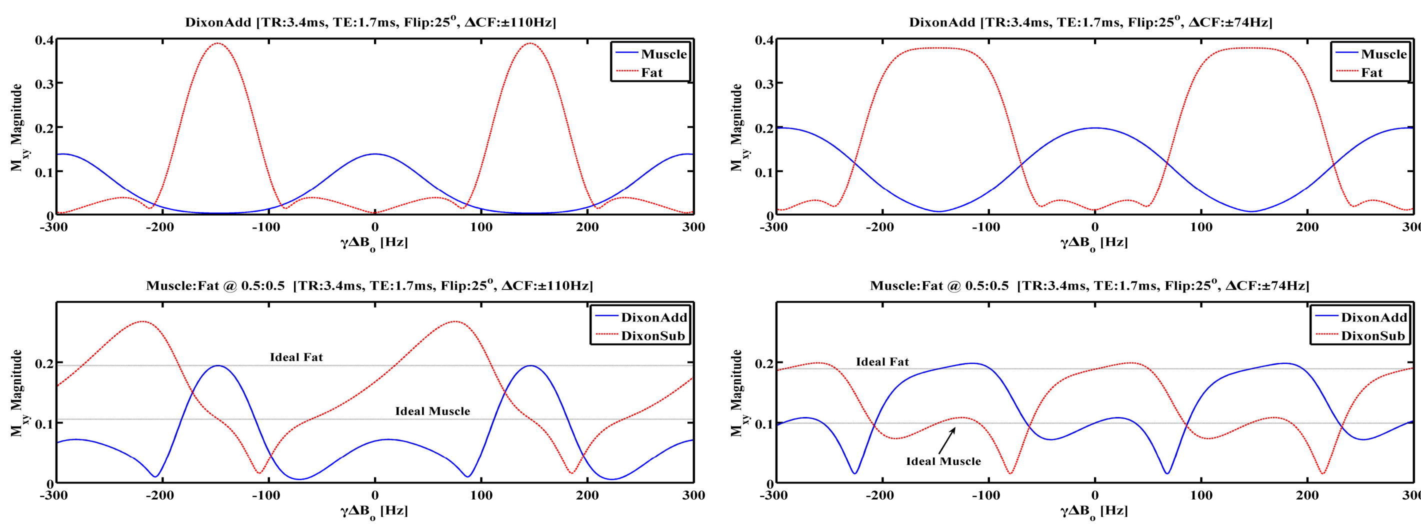

Figure: The upper row shows the Huang-Dixon complex addition results for pixels that contain only water or only fat. The left column is for CF offsets of ±110 Hz, while the right column is for CF offsets of ±74 Hz (±¼BW_{ssfp}). The lower row depicts both the complex addition and subtraction results for a pixel that contains 50% water and 50% fat. The 'Ideal Fat' and 'Ideal Muscle' horizontal lines represent the maximum signals for that tissue at their respective ±CF offsets.