A histogram-based two-point Dixon fat-water separation method

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Introduction: The conventional Dixon fat-water separation technique [1-4] relies on the acquisition of complex images with fat and water signals in-phase and 180° out-of-phase. The phase-shift between fat and water of the out-of-phase image ($\Delta\theta$) is commonly assumed to be exactly equal to π but this value is not verified experimentally. In this abstract, we propose a histogram-based fat-water separation method that measures the value of $\Delta\theta$ first, then uses it to separate fat and water. The performance of the proposed technique is demonstrated with a set of volunteer knee images.

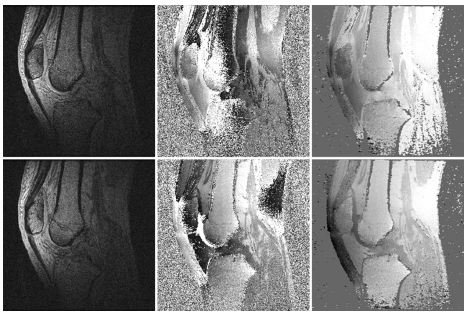

Figure 1. The in-phase (top row) and out-of-phase (bottom row) central sagittal slice from channel one. From left to right are the magnitude, the measured and the unwrapped phase images.

Theory: The two complex images S_1 and S_2, with fat and water in-phase and "quasi" out-of-phase, can be expressed as:

$$S_1 = (W + F)e^{i\phi_0} \quad (1)$$

$$S_2 = (W + Fe^{i\Delta\theta})e^{i(\phi_0+\Phi)} \quad (2)$$

where W and F are the water and fat components of the images, $\Delta\theta (\sim \pi)$ is a phase offset due to the chemical shift between fat and water, ϕ_0 is a constant for a given pixel, and Φ is a phase shift that includes the effects of magnetic field inhomogeneity and susceptibility-induced magnetic field changes. After the terms $exp(i\phi_0)$ and $exp(i\Phi)$ are eliminated (as described below), the separated water and fat images can be calculated as follows:

$$W = \left|(S_2' - S_1' e^{i\Delta\theta})/(1 - e^{i\Delta\theta})\right| \quad (3)$$

$$F = \left|(S_1' - S_2')/(1 - e^{i\Delta\theta})\right| \quad (4)$$

The proposed fat-water separation method is described as follows: 1) unwrap the phase maps of S_1 and S_2; 2) calculate the phase differences between two unwrapped phase maps, resulting in a phase-shift map; 3) fit the histogram of the phase-shift map with a double Gaussian function; 4) calculate the value of $\Delta\theta$ and the threshold value (TH_{fat}) from the fit; 5) for fat-like pixels (phase-shift > TH_{fat}) calculate $S_2' = |S_2| \times exp(i\Delta\theta)$, otherwise, $S_2' = |S_2|$; let $S_1' = |S_1|$; 6) use Eqs. 3 and 4 to extract fat and water images.

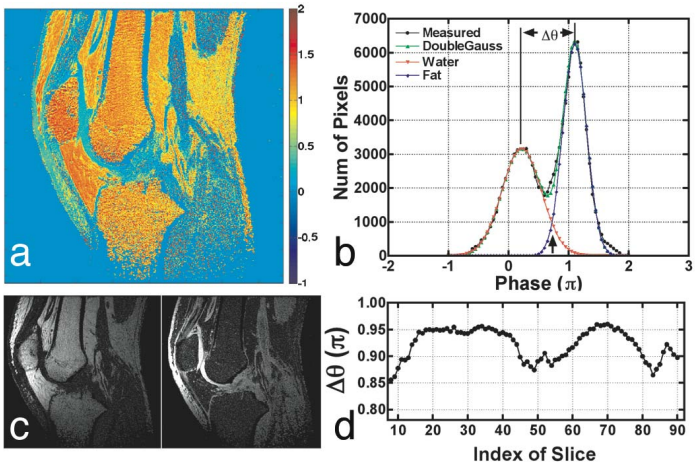

Figure 2. a) Colored phase-shift map calculated from Fig.1 (left column). b) Histogram of the phase shift map and the results of Gaussian fitting (the arrow indicates TH_{fat}.) c) Fat (left) and water (right) images. d) Measured Δθ.

Methods: A standard 3D SPGR pulse sequence was used to acquire in-phase and out-of-phase sagittal knee images of a healthy volunteer. The scanning parameters were: flip angle = 20°, field view = 16 cm × 12 cm, thickness = 1 mm, matrix size = 512 × 384 × 90. The first 6 slices were discarded due to extremely low SNR. All experiments were performed on a GE 3.0-T whole-body MRI scanner using a GE eight-channel knee coil. The proposed fat-water separation method was applied to each channel separately, then the sum of squares method was used to combine the fat and water images obtained from all channels. Phase unwrapping was achieved using an algorithm that uses a recursive orthogonal referencing approach (PUROR, submitted to MRM) to remove streaks that result following conventional 2D phase unwrapping. Processing was performed using MATLAB (USA).

Results and Discussion: Figure 1 demonstrates that the phase unwrapping technique successfully removed the phase aliasing for the in-phase and out-of-phase images. The phase map of Fig. 2 (a) clearly shows the phase shift between fat and water. Based on the analysis of the histogram (Fig. 2 (b)), the values of $\Delta\theta$ and TH_{fat} were determined and used to separate the fat and water (Fig. 2 (c)). Figure 2 (d) reports the values of $\Delta\theta$ over the 84 slices; the mean ± SD of $\Delta\theta/\pi$ is 0.92 ± 0.03. Figure 3 shows the results after combining all eight channels.

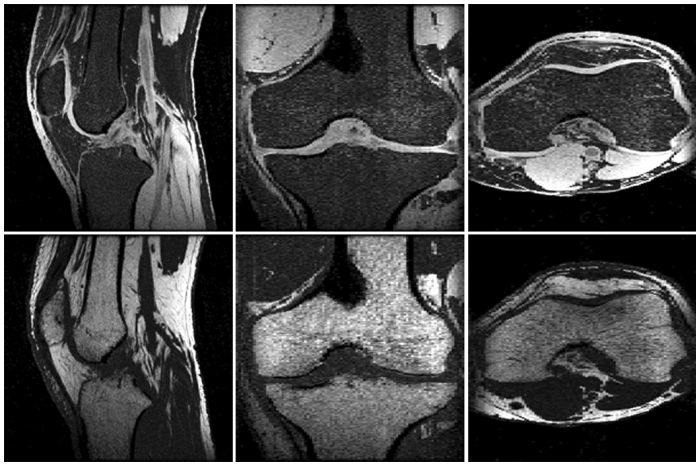

Figure 3. Top and bottom rows shows the fat and water images, respectively. From left to right are the sagittal, coronal and axial central slices.

This approach is the first to demonstrate that the in- and out-of-phase images are actually separated by $\Delta\theta \neq \pi$ and that the discrepancy is position dependent (Fig. 2(d)), making correction for the discrepancy difficult. The histogram in Fig. 2(b) shows that the FWHM of the fat distribution is 0.47π and that of water is 0.71π suggesting that for techniques that use partially opposite phase [5], care must be taken to ensure that the two peaks are separated by at least 0.6π.

In summary, the PUROR method represents a robust approach for two-point Dixon fat-water separation, without requiring perfectly opposite phase separation for fat and water.

References: [1] Dixon, Radiology 153:189-194, 1984. [2] Coombs, et al., MRM 38:884-889, 1997. [3] Szumowski, et al., Radiology 192: 555-561, 1992. [4] Ma, MRM 52: 415-419, 2004. [5] Xiang and An, JMRI 7: 1002-1015, 1997.