Water fat shift displacement artifact correction in two point Dixon imaging

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INTRODUCTION: The resonance frequency of protons in human methylene lipid $[CH_2]_n$ and water differ by 3,5 ppm corresponding to 224 Hz at a field strength of 1.5 T. This intrinsic difference can be utilized for effective fat and water separation using phase sensitive Dixon reconstruction [1]. Another consequence of the resonance frequency shift is the spatial misregistration in the frequency encoding direction known as the chemical shift artifact. In MRI the frequency is used to encode the spatial position of the signal. As the RF-pulse is tuned at the frequency of water, fat will have a relative frequency shift that cannot be distinguished from the phase difference introduced by the frequency encoding [2]. A flyback protocol [3] eliminates the problem as the misregistration is constant between acquisition times but decreases the signal to noise ratio (SNR). Another approach is to collect the data without flyback and iteratively compensate for the misregistration effect. A simple iterative solver has been implemented and is presented below.

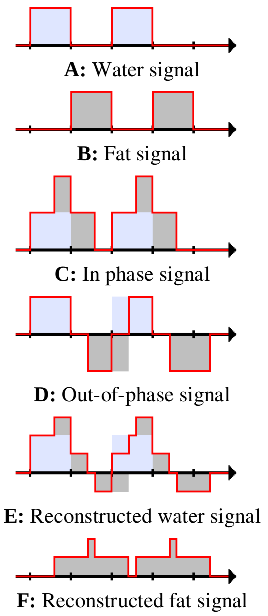

Figure 1: Chemical shift artifact effects on water and fat signals. The signal is red while fat/water contributions are in other colors.

METHODS: The signals from a two point Dixon acquisition after phase sensitive reconstruction (**Fig. 1C-D**) can be described as:

$IP = W(\delta) + F(\delta+chs)$

$OP = W(\delta) - F(\delta-chs)$

Combing the in- and out-of-phase signals should ideally provide separate water and fat volumes but the spatial misregistration introduced by the chemical shift artifact leads to (**Fig. 1E-F**):

$$0.5 \cdot (IP + OP) = 0.5 \cdot (2W(\delta) + F(\delta+chs) - F(\delta-chs)) \quad (1)$$

$$0.5 \cdot (IP - OP) = 0.5 \cdot (F(\delta+chs) + F(\delta-chs)) \quad (2)$$

where *W* and *F* are the true signals and *chs* the chemical shift. The consequence of the artifact is a low pass filtering effect in the extracted fat volume and a derivative contamination effect of the true fat signal in the extracted water volume. The fat/water shift is known which means that it can be compensated for, creating synthetic in-phase and out-of-phase volumes tuned at the methylene lipid frequency:

$IP' = IP(\delta-chs) = W(\delta-chs) + F(\delta)$

$OP' = OP(\delta+chs) = W(\delta+chs) - F(\delta)$

These equations yield alternative expressions for fat and water:

$$0.5 \cdot (IP' + OP') = 0.5 \cdot (W(\delta-chs) + W(\delta+chs)) \quad (3)$$

$$0.5 \cdot (IP' - OP') = 0.5 \cdot (2F(\delta) + W(\delta-chs) - W(\delta-chs)) \quad (4)$$

From (1) and (3) expressions for true fat and water signals can be extracted to create:

$$W(\delta) = 0.5 \cdot (IP + OP) - 0.5 \cdot K \cdot (F(\delta+chs) - F(\delta-chs)) \quad (5)$$

$$F(\delta) = 0.5 \cdot (IP'-OP') - 0.5 \cdot K \cdot (W(\delta-chs) + W(\delta+chs)) \quad (6)$$

where *K* is introduced for stabilisation purposes. Since the true fat signal is unknown the extracted low pass filtered fat volume from the initial guess. The following correction scheme is proposed:

1. Set the initial fat value: $F(x) = (IP(x) - OP(x)) \cdot 0.5$
2. Calulate the new water value from (5): $W(x) = 0.5 \cdot (IP + OP) - 0.5 \cdot K \cdot (F(x+chs) + F(x-chs))$

Calculate the new fat value from (6): $F(x) = 0.5 \cdot (IP' - OP') - 0.5 \cdot K \cdot (W(x-chs) + W(x+chs))$

Repeat from 2 until a specified criterion is met or a defined number of iterations are reached.

Without introducing the stabilization constant *K*, the solver does not converge. Redusing K to around 0.98-0.99 makes it stable and gives a full convergence in about 100 iterations. We are currently working on finding an explanation to why the theoretical equations are unstable.

RESULTS: The corrected water images (**Fig. 2F-G**) shows visible improvements compared to the original images (**Fig. 2A-B**). Most evident are the effects in the outer skin layer but it is also apparent in the region around the spine. The effects in the fat images (**Fig. 2C-D and 2H-I**) are harder to distinguish by visual inspection but by looking at the difference image (**Fig. 2J**), the sharpening effect of the reconstruction algorithm becomes clear.

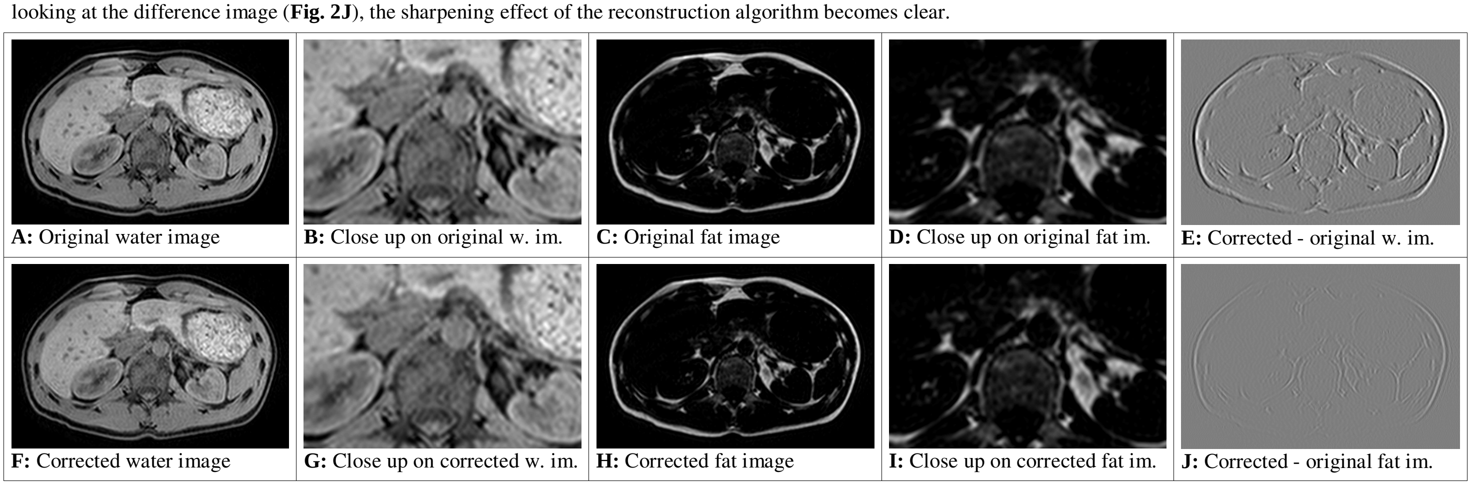

Figure 2: Original and reconstructed images after chemical shift artifact correction together with difference images created by taking corrected image - original image.

DISCUSSION: A simple iterative solver can efficiently be used to correct for the chemical shift artifact in a two point Dixon acquisition. The developed method is easy to implement and has shown promising results. Some work remains in finding the causes of the stability interference.

REFERENCES: 1. Dixon. Radiology,1984. p.189-194. **2.**Hood. RadioGraphics,1999. p.357-371. **3.**Cunningham. Magnetic Resonance in Medicine,2005. p.1286-1289.