Fat-water separation in dynamic objects, with a novel approach based on the Dixon and UNFOLD methods

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Introduction

This work aims at separating the fat and water contents of a dynamic object. Existing imaging strategies such as the Dixon method [1,2] and direct phase encoding [3] are capable of separating fat and water signals. But because these methods typically require at least 3 images for the separation to be performed, it may be difficult to achieve good temporal resolution, for dynamic objects. For example, if individual images could be acquired with a temporal resolution τ, the need to acquire 3 images for each (fat and water) time frame worsens temporal resolution by a factor of 3, to a value of 3τ. We propose to acquire time frames with the usual temporal resolution of τ, while modulating TE from time frame to time frame. We like to think of the approach as a fusion between the 3-point Dixon method, and the "unaliasing by Fourier-encoding the overlaps in the temporal dimension" (UNFOLD) [4] method. While UNFOLD shifts the sampling function from frame to frame to provide separation of aliased and non-aliased signals, our proposed approach instead shifts the value of TE from frame to frame to provide separation of fat and water signals. The aliased material is often assumed to not be very dynamic in UNFOLD [4], and similarly fat signal is assumed here to not be very dynamic. Even when this assumption is not well respected, removing at least the low temporal frequencies of the fat signal is expected to allow significant fat suppression, in the water images. Preliminary results in a phantom are shown here, obtained with a 2D SSFP cardiac sequence.

Theory

The time series of images *I(t)*, obtained when imaging a dynamic object containing both fat and water signal, is given by:

$$I(t) = [W(t) + F(t)\exp(i\Delta\omega TE(t))]\exp(i\gamma\Delta B_{\circ}(t)TE(t)), \qquad [1]$$

where *W(t)* and *F(t)* represent the water and fat components, respectively, $\Delta\omega$ is the difference in Larmor frequency between fat and water (times 2π), and ΔB_o is the magnetic field inhomogeneity. The value of TE is changed from one time frame to the next, over our 20-frame series. The TE variations, $\Delta TE(t)$, are plotted in Fig. 1. Because SSFP sequences typically have very short values for TR and TE, ΔTE is kept much smaller than the 2.2 ms required to inverse fat signal with respect to water signal ($\Delta TE \leq 0.8$ ms, Fig. 1) [5], and for this reason an approach inspired from the direct phase encoding method [3] was used as part of the reconstruction. Grouping time frames 3 by 3, a low-temporal resolution estimate of the field inhomogeneity, $\Delta B_o(t)$, can be obtained. This estimate is used to cancel the right-most term in Eq. 1, yielding a corrected version of *I(t):*

$$I'(t) = W(t) + F(t)\exp(i\Delta\omega TE(t)). \qquad [2]$$

After a Fourier transform through time, *W(t)* is found centered at DC, while *F(t)* is in part displaced toward higher temporal frequencies, due to the modulation $\exp(i\Delta\omega TE(t))$. In other words, the fat component is forced to behave in time in a way dictated by *TE(t)*. Temporal analysis is used to recognize this temporal behavior, to identify fat signal. Water images, *W(t)*, are then obtained simply by subtracting $F(t)\exp(i\Delta\omega TE(t))$ from $I'(t)$ (as seen from Eq. 2).

Results

20 time frames were obtained in a saline/oil 3-cm phantom, on a 1.5 T GE scanner (3.2 ms $\leq$ TE $\leq$ 4 ms, matrix size=256x256), and time frame #1 is shown in Fig. 2a. Temporal frequency spectra for 2 particular pixels are shown, one with water signal (Fig. 2d), and the other one with fat signal (Fig. 2e). Even small variations in TE ($\leq$ 0.8 ms) were sufficient to bring significant energy toward higher temporal frequencies, in fat material (red arrows in Fig. 2e). This higher-frequency (complex) signal acts as a fingerprint for detecting the presence of fat, through temporal analysis. Figure 2c shows the signal identified as fat. The first time frame (out of 20) for the water content is shown in Fig. 2b. Figure 3 shows the static version of the field map.

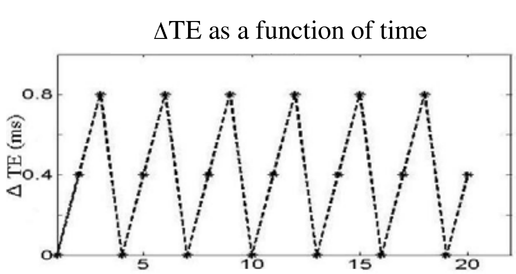

Figure.1

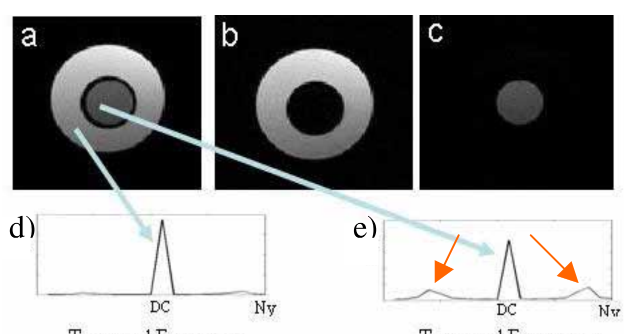

Figure.3

Field Map

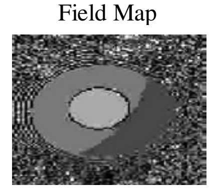

Figure.3

Conclusion

A novel approach for fat-water separation in dynamic objects was presented, and tested in a saline/oil phantom.

References [1] Dixon, *et al Radilogy* (153)189-194(1984). [2] Glover, *et al.* MRM (18)371-383(1991). [3] Xiang, *et al*. JMRI (7):1002-1015(1997). [4] Madore, *et al.*MRM (42):813-828(1999). [5] Reeder, *et al.*MRM (180)357-362(2003).