Fat-water separation in dynamic objects, applied to cardiac cine imaging.

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Introduction: This work aims at separating the fat and water contents of dynamic objects, by distributing the acquired fat signal over the temporal frequency domain and applying appropriate filters to discriminate fat and water. Existing imaging strategies such as the Dixon method [1] and direct phase encoding (DPE) [2] are capable of separating fat and water signals. 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. Our proposed approach acquires time frames with the usual temporal resolution, and modulates TE from time frame to time frame. While a method like UNFOLD shifts the sampling function from frame to frame to provide separation of aliased and non-aliased signals, our approach instead shifts the value of TE from frame to frame to provide separation of fat and water signals. Aliased materials are sometimes assumed to not be very dynamic in UNFOLD [3], and similarly, fat signal is assumed here to not be very dynamic. Even for dynamic fat signal, removing at least the low temporal frequencies is expected to enable significant fat suppression in the water images.

Theory: The time series of images $I(\vec{r},t)$, obtained when imaging a dynamic object containing both fat and water signal:

$$I(\vec{r},t) = [W(\vec{r},t) + F(\vec{r},t)e^{i\Delta\omega TE(t)}]e^{i\gamma\Delta B_o(\vec{r},t)TE(t)} \quad (1)$$

where $W(\vec{r},t)$ and $F(\vec{r},t)$ represent the water and fat components, respectively, $\Delta\omega$ is the difference in Larmor frequency between fat and water (times 2π), and $\Delta B_o(\vec{r},t)$ is the magnetic field inhomogeneity. To estimate the field map, DPE [2] is quite effective, especially when TE increments are small [2,5]. The proposed method is based on the acquisition of N images, with a periodicity of four (Fig. 1b); therefore, to estimate the field map, images can be grouped 4 by 4. This low-temporal resolution estimate the field map is used to cancel the right-most term in Eq. 1, yielding a corrected version of $I(\vec{r},t)$:

$$I'(\vec{r},t) = [W(\vec{r},t) + F(\vec{r},t)e^{i\Delta\omega TE(t)}] \quad (2)$$

A cine SSFP sequence, with short TR and TE, is used here. The sequence was modified so the echo time changes from cardiac phase to cardiac phase, while keeping TR constant (Fig. 1b). The image pixel value (Eq. 2) changes as a function of cardiac phase and the FFT of this function gives a temporal frequency spectrum, where FFT$(W(\vec{r},t))$ is centered at DC, while FFT$(F(\vec{r},t))$ is distributed over a range of higher frequencies (Fig. 1a), 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 $TE(t)$. To identify the fat signal, a temporal analysis analogous to the one in [4] is used to recognize the temporal behavior of fat, and separate it from water. While the procedure in [4] separates aliased and non-aliased signal, here instead it is used to separate the water and fat signals, based on the $\exp(i\Delta\omega TE(t))$ signature imposed to fat.

Results: A cardiac phase series of images was obtained in a healthy volunteer, on a 3 T GE scanner, $TE_{1,2,3,4}$ = 1.7, 2.5, 1.7, 2.1 ms, TR = 4.7 ms, matrix size = 192x160, Fig. 2 shows calculated water and fat components, for short axis cine images from a systolic frame (a - c) and a diastolic frame (d - f). Fig. 1a shows that even small variations in TE (≤ 0.4 ms) were sufficient to bring significant energy toward higher temporal frequencies in fat material (red arrows in Fig. 1a), allowing fat-water separation.

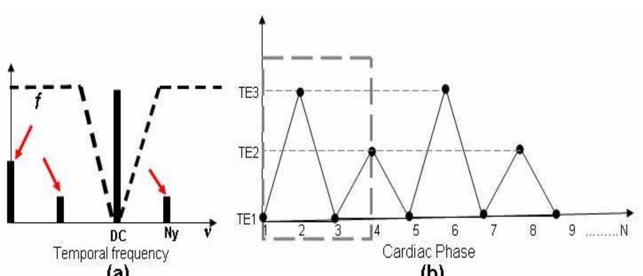

Fig.1

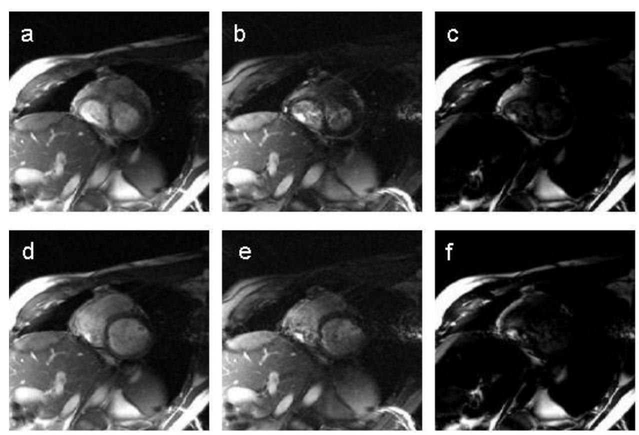

Fig. 2: Systolic (a-c) and diastolic (d-f) cardiac cine images, where (b,e) feature water content and (c,f) fat content.

Conclusion: A technique for fat-water separation in dynamic object was implemented successfully, in a cardiac cine application.

References:

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Acknowledgments: Grant number R01 HL073319, and U41 RR019703-01A2.