Single Acquisition Water Fat Separation for SSFP Cardiac CINE Imaging: Feasibility Study

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Introduction: Fat suppression is routinely used in clinical MRI. The 3-point Dixon water and fat separation technique is one of several fat suppression methods developed [1]. It has shown its ability to provide more uniform separation results than other methods such as frequency selective saturation pulses and spectral-spatial pulses because it incorporates the local field inhomogeneity factor of each pixel in the algorithm and corrects for it. However, it increases the scan time three-fold and limits the echo times or echo shifts at specific values (multiples of π).

A recently proposed Dixon technique [2] has relieved the limitation of conventional Dixon partially by allowing arbitrary echo time shifts. This method opens the possibility of water fat separation for previously challenging pulse sequences, such as SSFP sequences. However, it still requires three acquisitions, which increases the scan time by three fold. Based on the new idea in [2], we propose a single acquisition separation algorithm. Our goal is to achieve uniform fat-water separation with the ability to correct for field inhomogeneity with no increase in scan time. This technique would be particularly valuable for applications that are sensitive to scan time, such as cardiac CINE imaging, where increased scan time leads to a long breath hold, and possibly motion artifact. In this work, we will illustrate the feasibility of a single acquisition water fat separation method in the context of SSFP Cardiac CINE imaging.

Method Water and fat spins rotate at different resonance frequencies. Let θ_d denote the evolution of phase difference of water and fat at echo time TE. Therefore, the signal received can be modeled as: $S(TE) = (W + F \cdot e^{j\theta_d})e^{j2\pi(\psi TE+\psi_0)}$. In this equation, W and F represent water and fat components in this pixel, and are considered real numbers. ψ represents the local B0 field inhomogeneity, and ψ_0 denotes the initial phase of the signal at time zero, which can be also interpreted as the common phase of water and fat, due to B1 field inhomogeneity, k-space sampling shift and other scanner related factors. For SSFP, θ_d at time TE is expected to be: $2\pi\Delta f(TE - TR/2)$, where Δf is the chemical shift of fat relative to water. An offset of TR/2 is used because SSFP has been shown to have nearly spin echo behavior [3]. In order to separate water and fat with only one acquisition, θ_d should not be 0 or π, in which case, water and fat is aligned and thus it is not possible to differentiate them. Although separation at any other θ_d value may be theoretically feasible, it is easily appreciated that when θ_d is $\pm\pi/2$, the separation will be optimal in terms of noise performance. Therefore, we will choose TE and TR such that θ_d is close to $\pm\pi/2$. Assuming that ψ and ψ_0 have been obtained, by demodulating the signals with the known ψ and ψ_0, the water and fat will be pushed into two orthogonal channels and thus can be separated.

To find ψ and ψ_0, we will perform a preliminary acquisition phase before the CINE imaging, where three echoes will be acquired and the method in [2] will be used. This set of ψ and ψ_0 then is repeatedly used in all other CINE phases, based on the assumption that both ψ and ψ_0 are slowly time varying over the cardiac cycle [4].

To demonstrate the feasibility of our method, we acquired four SSFP CINE slices using the method in [2] on a GE CV/I 1.5T scanner (GEMS, Milwaukee, WI), with TE = [0.8ms, 1.25ms, 2.6ms], TR = 4.7ms and 20 phases through the cardiac cycle per slice. The first phase was used as the preliminary phase, where the source images were smoothed and a 3-pt Dixon reconstruction was performed to extract the phases ψ and ψ_0, which would be spatially slowly varying because of the source smoothing operation. The proposed single acquisition water-fat separation then is conducted with the signals only from the 2nd echo at each phase helped by ψ and ψ_0 previously obtained. The results are compared with those reconstructed using all three echoes (3-pt Dixon). Echo 2 is chosen because the corresponding θ_d is at the optimal value, $-\pi/2$.

Results Figure 1 shows the separation results from one of the slices. As described above, the 3-pt Dixon reconstruction is carried out at the first phase, which provides field map ψ (a) and signal initial phase ψ_0 (b). As can be seen, the field map ψ is fairly smooth in regions with strong signal. Reconstruction of 3-pt Dixon at all 20 phases shows that the field map is also slowly time varying (not shown here). The initial signal phase ψ_0 has approximately 2 cycles of phase roll in the frequency encoding direction (right-left) while is relative stable at the phase encoding direction (up-down), which suggests the cause is a k-space sampling shift in the read-out direction. (c) and (d) show the 3-pt Dixon separation results at the first phase for comparison with single acquisition separation results (e), (f). It can be seen that the proposed method achieves successful separations with only 1/3 of the data. The separation results of a later phase (11th phase, (g) and (h)) show that the separation doesn't degrade from the first phase, which justifies the method of recycling the previously acquired ψ and ψ_0.

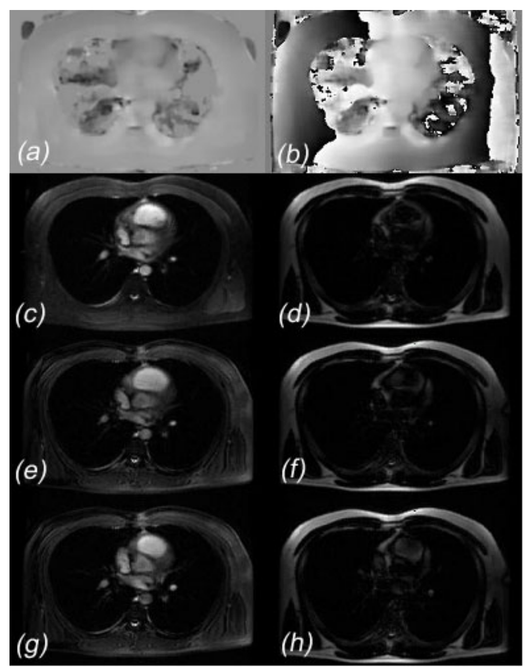

Figure 1: Separation results with a SSFP CINE data set. (a) and (b): field map and initial signal phase extracted from the 3-pt Dixon reconstruction at the first phase. (c) and (d): separated water and fat at the first phase using all three echoes. (e)-(h): separated water and fat using only the second echo at: (e) and (f), the first phase, and (g) and (h), the 11th phase.

Discussions We have shown the feasibility of a single acquisition water-fat separation scheme, using the SSFP cardiac CINE imaging as the example. However, it can be also applied in many other pulse sequences and applications to help decrease scan time or increase the temporal resolution. Dynamic imaging is of particular interest because phases are relatively stable across the imaging time. Examples include bolus perfusion tracking for breast imaging [5], and MR guided breast biopsy, which will benefit significantly from fat suppression. The cost with respect to the 3-pt Dixon is a loss of SNR, but to a level comparable to conventional single excitation CINE imaging.

In our demonstration with SSFP CINE data, we used the first cardiac phase as the preliminary phase. In a final implementation, the preliminary frame would be a separate ungated scan, and may be acquired in a low resolution form to add minimum overhead.

Conclusion The proposed single acquisition water-fat separation scheme achieves successful separation on cardiac SSFP CINE data sets by using field map and phase information for all subsequent images in the acquisition. It has potential for many dynamic applications that rapidly acquire images at the same location and require uniform fat suppression.

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