Multi-channel T_2* IDEAL for Water Fat Separation with Prior Optimized Phase

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Introduction

Multiecho chemical shift-based water-fat separation methods have great potential in fatty liver disease diagnosis [1]. The complex-fitting methods developed by Yu et al can quantify water/fat contents, T_2* and B_0 field inhomogeneity maps simultaneously [2,5]. Multi-channel RF coil is widely used for signal acquisition due to its high signal to noise ratio (SNR) and extended coverage. However, traditional water-fat separation method is computation intensive if each channel data is processed individually [2], especially when acquisition matrix is big. More importantly, individual channel data processing performs poor off the center of coil sensitive foci due to intrinsic low SNR. Combination of multi-channel images with the help of sensitivity maps prior to final fat-water separation can solve the problem. However, it is hard to get phase sensitivity maps precisely because of chemical shift between fat and water. The methods proposed previously [3, 4, 5] were only applied to pure water cases. Thus this work aims to investigate a new method which can combine multichannel images optimally before performing the complex-fitting based water-fat separation. This method does not require in- or out-phase between water and fat. Therefore, the echo shift across echoes can be flexible.

Theory

We use the following signal model for water-fat analysis: $S_i(t) = \left(\rho_w + \rho_f \sum_{k=1}^{3} \alpha_k e^{j2\pi f_k t}\right) e^{j(2\pi\varphi t + \theta_i)} + n_i$. Here $S_i(t)$ is the signal from the ith coil. n_i is the white Gaussian noise from the ith coil. ρ_w and ρ_f are the intensities of water and fat respectively. f_k is the frequency offset of the kth fat peak relative to water, and α_k is the corresponding relative amplitude. Only three main fat peaks are considered here thus $\sum_{k=1}^{3} \alpha_k = 1$. φ represents the B_0 field inhomogeneity and θ_i is the phase offset map of the ith coil. For data processing, firstly low resolution ρ_w and ρ_f from down sampled images are estimated using the traditional method. Full resolution ρ_w and ρ_f of are then estimated by interpolation and the phase introduced by $\varepsilon = \left(\rho_w + \rho_f \sum_{k=1}^{3} \alpha_k e^{j2\pi f_k t}\right)$ is estimated and removed from $S_i(t)$. Then two echo images at t_a, t_b of each channel were selected to estimate θ_i by solving

equations: $\begin{cases} S_i'(t_a) = A e^{j(2\pi\varphi t_a + \theta_i)} \\ S_i'(t_b) = B e^{j(2\pi\varphi t_b + \theta_i)} \end{cases}$ where $S_i'(t)$ is the source signal with ε removed. A and B are the magnitude of

$S_i'(t_a)$ and $S_i'(t_b)$ respectively. Then $P = \left((S_i'(t_a))^\mu / S_i'(t_b)\right)^{1/\mu-1}$, $\mu = t_b/t_a$, and $e^{j\theta_i} = P/|P|$. The phase map that divided by $e^{j\theta_i}$ of each channel could be combined using weighted average methods [4]. The magnitude part of the combined image is formed by the Sum of Square (SOS) method. Fig. 1 is the flow chart of this algorithm. The complex-fitting method can be then performed on this combined image.

Methods

Both phantom and *in vivo* images were acquired on a 3T scanner (Achieva, Philips Medical System) to compare evaluate our new algorithm and the traditional method. *In vivo* data was acquired on a liver of a healthy volunteer without fatty liver. The *in vivo* imaging parameters were: FOV=224mm×160mm, TR=25ms, TE_1=1.51ms, △TE=0.6ms, voxel size=1.5mm×1.5mm×8mm. A 32 channel SENSE Torso coil was used. For phantom test: FOV=140mm×180mm, TR=25ms, TE_1=1.51ms, △TE=0.6ms, Voxel size=1mm×1mm×5mm using 8 channel head coil.

Results

Fig. 2 shows the *in vivo* fat ratio results. The computation time using our algorithm costed 80.9 s while the traditional method costed 514s to process the *in vivo* data. The phase map of the combined map from all channels got smoother comparing with individual channel data (Fig. 2a and b). The fat ratio of the circled part of the liver is 3.3% by our method and 7% by the traditional method. The fat ratio of the arrow pointed area (subcutaneous fat) was 95% by our method and 93.2% by the traditional method. The phantom test results in Fig. 3 show that the result of our method is generally smoother and has better noise-resistant performance for pure fat and water area compared with the traditional method.

Discussion and Conclusion

Our algorithm is based on an assumption that water and fat are in-phase at TE=0. Small deviation can be acceptable due to the robustness of six echoes complex-fitting methods. The proposed algorithm performs poorly in regions pointed by red arrow in Fig. 2b, which is surrounded by noise area. The interpolation accuracy is deviated by the noisy information. For such cases, robust masking procedure thus is necessary. Other extra procedures can be employed to further improve the performance of the algorithm. One is to iteratively perform the last two steps in Fig 1 (dashed line), until the calculation result becomes stable. The iterative calculation is especially efficient for combined data. Additionally, more echo pairs can be used for θ_i more precise estimation. In conclusion, our method can not only greatly shorten the calculation time but also improve the quantification accuracy. This method is not limited by echo times.

Reference [1] Bley et al, JMRI 2010; 31:4–18 [2]. Reeder et al, MRM 2004; 51:35-45. [3]. Hammond et al, NeuroImage 2008; 39:1682–1692. [4] Robinson et al, MRM 2011; 65: 1638–1648. [5]. Yu et al, MRM 2008; 60:1122–1134.
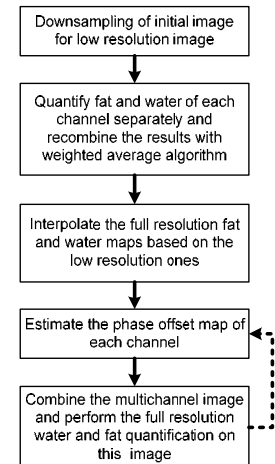
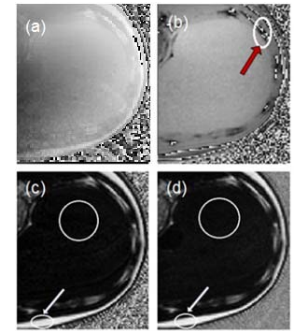Fig.1 Illustration of the steps of our methods.

Fig. 2 The calculate results using two Methods. a is the phase map of a single channel that has the best coverage of the part shown b is the full resolution combined phase image of liver. c is the fat-ratio map using our method and d is the fat-ratio map using traditional method.
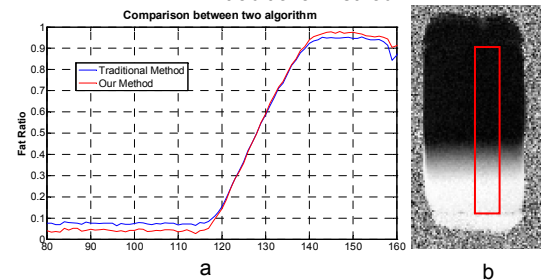

Fig. 3 b is the fat-ratio map of the phantom, and the red rectangular indicates the fat-ratio shown in b. the result of our method(red line) is more smooth and has better noise-resistant performance compared with the traditional method(blue line).