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]. Multichannel 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 multichannel 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: $s(t) = \left( s_0 + s_1 \epsilon^{i(2\pi f_0 t)} \right) e^{i(2\pi f_1 t)} + n_t$. Here $s(t)$ is the signal from the $t$th coil, $n_t$ is the white Gaussian noise from the $t$th coil, $s_0$ and $s_1$ are the intensities of water and fat respectively, $f_0$ is the frequency offset of the $t$th fatty peak relative to water, and $c$ is the corresponding relative amplitude. Only three main fat peaks are considered here thus $\sum_{t=1}^{3} c_t = 1$, $a_t$ represents the $B_0$ field inhomogeneity and $\theta_t$ is the phase offset map of the $t$th coil. For data processing, firstly low resolution $s_0$ and $s_1$ from down sampled images are estimated using the traditional method. Full resolution $s_0$ and $s_1$ are then estimated by interpolation and the phase introduced by $c = \left( s_0 + s_1 \epsilon^{i(2\pi f_0 t)} \right) e^{i(2\pi f_1 t)}$ is estimated and removed from $s(t)$. Then two echo images at $t_1$ of each channel were selected to estimate $\theta_t$ by solving equations $\left( \frac{s(t_1)}{s(t_2)} = A(\epsilon^{i(2\pi f_0 t_2)} + A(B_0) \epsilon^{i(2\pi f_1 t_2)} \right)$, where $s(t)$ is the signal source with $c$ removed. $A$ and $B$ are the magnitude of $s(t_1)$ and $s(t_2)$ respectively. Then $P = \left( s(t_1) \right)^{\frac{1}{2}} \left( s(t_2) \right)^{\frac{1}{2}} \epsilon^{-i \theta}$, $\mu = t_2 / t_1$, and $\epsilon^{i \theta} = P / |P|$. The phase map that divided by $\epsilon^{i \theta}$ of each channel can 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=0.6ms, Voxel size=1mm×1mm×8mm 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) is 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 $\theta$ 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.

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Reference