

Water Fat Separation from a Single Spatiotemporally Encoded Echo Using k-space Peaking and Joint Regularized Estimation

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Purpose

Reliable separation of the water and fat signals is of considerable clinical significance for improving the conspicuity of abnormalities or diagnosing the fatty infiltrative diseases. The main challenge for a Dixon technique lies in determining the phase error. After the IDEAL method was put forward in 2004 [1], more researches have been made on the development of analytical solutions of the phase error map because they are less sensitive to noise and more robust for large scale of field inhomogeneity variation. However, many efforts were focused on multi-echo solutions, which although ensure the accuracy of the results but usually require longer acquisition time and are more error-prone to patient motions and system instabilities. Recently, a new technique was proposed for discriminating water and fat from a single spatiotemporally encoded (SPEN) echo [2]. Its original solution was based on joint linear least squares estimation of the water and fat profiles in each SPEN signal line. But the resolution was only one half of the original image. The study is aimed at presenting a new estimation algorithm which can improve the sensitivity and contrast of the output images without sacrificing their definition.

Theory and Methods

In terms of the convolution algorithm for SPEN imaging [3], performing Fourier transform on the demodulated signal integral yields the nominal k-space profile which can be viewed as the spectrum of the chemical composition in the specimen as the chemical shift differences are manifested by discrete offsets between peaks (Fig. 1). The water and fat frequencies are evaluated by peaking; then with spatial smoothness regularization in the form of first order finite difference, the water/fat profiles in each line can be estimated. A residual linear phase from the misclassified component will be superimposed on the estimated phase distribution of the other component around the region where intermingling occurs; and conversely, if the solution is generally correct, the output phase approximates to a constant because the frequency swept excitation usually delivers spatially uniform background phase due to the intrinsic immunity of the chirp pulse to RF field inhomogeneity. Therefore, by evaluating the linearity of the output phase, the erroneous voxels can be identified and constrained with adaptive filtering regularization in the second estimation for better output. The effectiveness of the new water fat separation approach is verified with phantom and in vivo rat experiments on a 7T Varian MRI system.

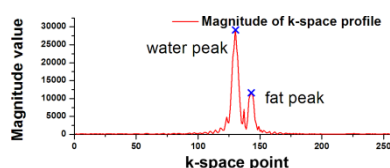


Fig. 1. The k-space profile for evaluating frequencies of water and fat.

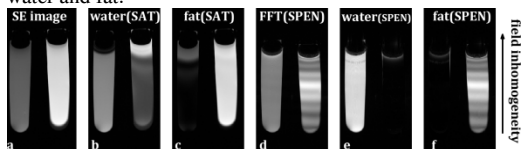


Fig. 2. Comparing results from presaturation method and the proposed method on two tubes filled with water or oil.

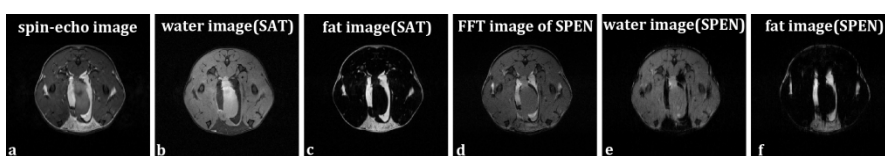


Fig. 3. Comparing results from presaturation method and the proposed method on lower abdomen of rat.

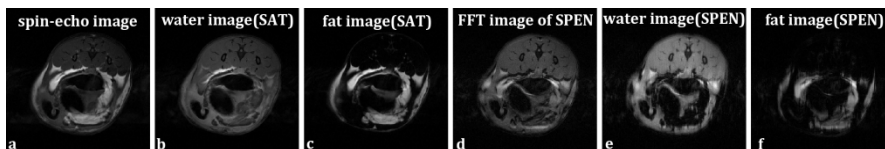


Fig. 4. Comparing results from presaturation method and the proposed method on upper abdomen of rat.

Results and discussion

For the phantom experiment in Fig. 2, the field inhomogeneity led to inconsistent fat/water suppression with presaturation method especially around the lids (Figs. 2b and c), but did not impair the results from the new method (Figs. 2e and f). The streaks in the oil tube were due to the spatially dependent phase differences between the olefinic and methylene fat which is an intrinsic feature of SPEN chemical shift imaging. In Fig. 3, the new method (Figs. 3e and f) delivered comparable image quality to the conventional method (Figs. 3b and c) except for a few swaps at the subcutaneous fat. In Fig. 4, with conventional method, the fat image (Fig. 4c) is of good quality but the prominent fatty residual on the upper border of the central cavity severely impairs the conspicuity of the water image (Fig. 4b). With the new method, although no motion compensation was attempted, the overall validity of the results was ensured. The visualization of tissues is also largely improved albeit some fatty infiltration in the water image (Fig. 4e) and fatty leakage in the fat image (Fig. 4f). However like the other single-echo methods, the new one is also based on the assumption that the voxel of considerable signal intensity is water or fat dominant, therefore ambiguities are present when imposing the filtering constraint at the boundaries of the two types of regions without knowing the relative signal ratios in these voxels. The chemical shift displacement at high field along the readout direction usually gives rise to severe misregistration of the two signals, exacerbates the local ambiguities by fabricating pseudo regions of water-fat mixture where the adaptive filtering constraint is less reliable or even infeasible, and produces defects in these areas. Moreover, in regions where the local field inhomogeneity deviates from the value estimated through k-space peaking, misclassification also may occur. Therefore more robust algorithm is required on the vulnerable voxels. Another point is to remove the spatially modulated streaks in the fat images, although this phenomenon only exists when considerable olefinic content is present in fat, which is not the case for most body tissues.

Conclusion

The experiments demonstrate that the new technique can achieve high-quality water fat separations in cases with disconnected fragments, considerable field inhomogeneity and moderate motion artifacts which are all challenging for the conventional methods. Because the proposed technique is based on a single echo with minimized T_2^* effects, it is potentially a viable alternative to the conventional water fat separation methods after further optimization on the processing algorithm.

Acknowledgement

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References

- [1] S.B. Reeder, et al, MRM, 51 (2004) 35-45. [2] R. Schmidt, et al, MRM, 70 (2012) 382-391. [3] C. Cai, et al, JMR, 228 (2013) 136-147.