Multi-Echo balanced SSFP Imaging for Iterative Dixon Reconstruction

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Introduction

In some imaging applications it is desirable to separate few metabolites with high spatial resolution in short imaging time. While spectroscopic imaging provides high spectral resolution, it requires long acquisition times and suffers from low spatial resolution. Echo planar spectroscopy imaging (EPSI) has been used for rapidly generating spectroscopic images with high spatial and moderate spectral resolution [1] based on gradient echo and fast spin echo imaging. Recently, an EPSI based multi-echo balanced SSFP (bSSFP) approach has been presented. While the reconstruction of this acquisition is rather simple, the method does not provide corrections for local distortions in the field map. Reeder et al. have demonstrated a novel iterative 'Dixon'-type reconstruction technique that requires $N + 1$ gradient echo measurements for the separation of N metabolites including corrections for local off resonances [2]. It also allows for very short TE increments and does not require phase unwrapping. Here we present an improved acquisition for this method as a multi-echo bSSFP sequence is used instead of repeated excitations and sampling with shifted echoes. To further improve the acquisition efficiency, a 'balanced' reference scan for echo-planar imaging [3] was acquired so that the odd and even echoes could be coherently used for image reconstruction. A phantom experiment for the separation of three metabolites and an in vivo exam for the separation of water and fat are demonstrated.

Methods

A multi-echo balanced SSFP sequence as shown in Fig. 1 was implemented on a 1.5 T Sonata system (Siemens Medical Solutions, Erlangen, Germany) with gradients supporting 40 mT/m amplitude and 200 T/m/s slew rate. In this acquisition, the phase encoding gradient is played out only once after each excitation such that the alternating readout gradient encodes a k-space line at multiple echo times. The acquisition of odd and even echoes causes two problems: (1) chemical shift artifacts will appear in opposing directions along the readout direction and (2) gradient delays, eddy currents, and other reasons will cause data inconsistencies between odd and even echoes. The first effect can be overcome with high bandwidth acquisitions. The second effect is well known as ghost artifacts in EPI. It is frequently modeled as an echo shift causing phase differences in the images which is decremental to a phase sensitive reconstruction. A simple solution is an individual reconstruction for the odd and for the even echo train, requiring the acquisition of twice as many echoes with an effectively doubled echo spacing between the images used for metabolite separation. Instead, we corrected the inconsistencies with the 'balanced' reference method [3]. A phantom experiment with bottles of water, vegetable oil (Δf = -230 Hz), and acetone (Δf = -130 Hz) was performed with the following parameters: 6 echoes, ΔTE = 1.28ms, TR = 10.3 ms, FOV = 30x30 cm^2, Δz = 10 mm, BW = 1220 Hz/pixel, acq. matrix = 256x256, tip = 60 deg. In addition, the knee of a healthy volunteer was scanned with the imaging parameters adjusted for the separation of fat and water: 4 echoes, ΔTE = 1.12 ms, TR = 7.3 ms, FOV = 30x30 cm^2, BW = 1150 Hz/pixel, acq. matrix = 256x256, tip = 60 deg.

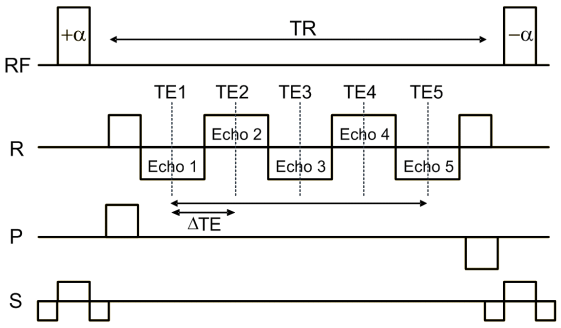

Fig. 1: Pulse sequence diagram for the multi-echo balanced SSFP sequence with five echoes and a spacing ΔTE.

Results

The results of the phantom experiment are shown in Fig. 2 and displayed as the magnitude image of the first echo (a) and metabolite maps for water (b), acetone (c), and fat (d). Fig. 3 shows water (a) and fat (b) images from the in vivo study. Please note that all metabolic images are scaled individually for best display results.

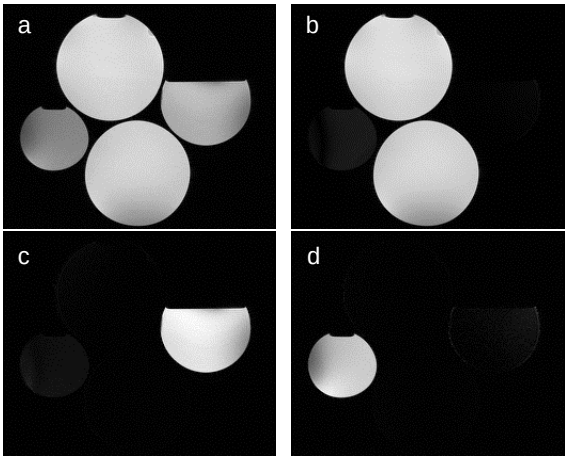

Fig. 2: Iterative Dixon reconstruction for a phantom with water, aceton, and fat and an echo train length of 6.

Conclusion

This study demonstrates the feasibility of metabolite separation with a multi-echo bSSFP sequence and an iterative 'Dixon'-type reconstruction to provide high SNR in short acquisition times. The different metabolites were well separated in the phantom study and the in-vivo experiment. The multi-echo acquisition has a much higher sampling efficiency as multiple single echo acquisitions with shifted echoes. In both acquisitions, the feasible length of the repetition time is ultimately limited by the quality of the shim over the FOV because large off-resonances will lead to banding artifacts in bSSFP imaging. A detailed analysis for an SNR optimized echo spacing can be found in [2].

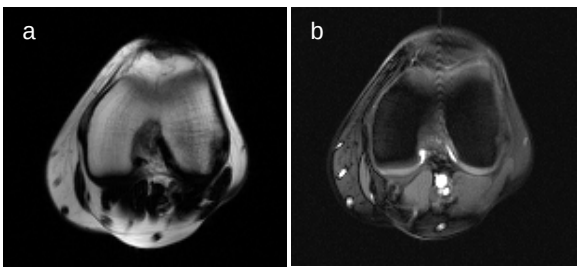

Fig. 3: Fat (a) and water (b) image of a human knee reconstructed from an acquired echo train length of 4.

References

[1] S Posse *et al., MRM* **33**:34-40, 1995.

[2] S Reeder *et al., MRM* **51**:35-45, 2004.

[3] S Reeder *et al., JMRI* **9**:847-52, 1999.