Efficient T2*- Contrast Manipulations in 3D Abdominal Imaging using Autocorrected Forward/Reverse Spiral MRI

P. Börnert[1], P. Koken[1], and H. Eggers[1]
[1]Philips Research Europe, Hamburg, Germany

Introduction

Besides large volume coverage and short total scan times, image contrast is very important in abdominal MRI. Fat suppression is often required and different T2* weightings are desired for different contrasts in gradient echo acquisitions. Very short and very long TEs facilitate the relevant contrasts of interest for the detection of dedicated contrast media, hemorrhage, iron deposition in the liver and other organs. Spiral imaging [1] is a very efficient and flexible sampling scheme, allowing for very short TE, via forward [1], and very long TE, via reverse sampling [2], in a given TR. But the spiral also shows high sensitivity to off-resonance effects (ΔB_o and chemical shift) [3], resulting in severe image blur. Usually, the performance of the suppression is compromised by main field inhomogeneity. But, chemical-shift encoding approaches represent an alternative allowing to separate chemical shift effects from ΔB_o, facilitating water/fat separation and off-resonance corrected non-Cartesian imaging [4-6]. In this work this concept was applied to show that efficient 3D single breath-hold, fat-suppressed, off-resonance corrected reverse and forward spiral imaging can be performed in abdominal applications with large volume coverage and tailored T2* contrast.

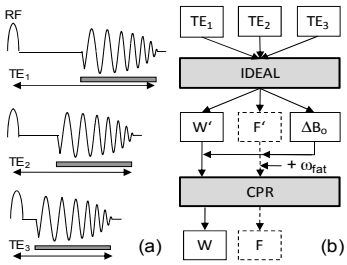

Fig.1. Spiral three-point Dixon fat suppression / separation and off-resonance correction. (a) Encoding scheme for the reverse spiral, (b) DIXON-CPR post-processing (separation / correction) for water (W) data, optional for fat (F) data.

Methods

Spiral gradient echo imaging was performed using chemical shift encoding with a fixed k-space trajectory, which was shifted in time to sample three individual echoes (see Fig.1a). IDEAL [7] was applied to the reconstructed spiral images to separate water and fat signal contributions followed by a Conjugate Phase Reconstruction (CPR) [3] using the estimated field map to deblur the water image (see Fig.1b). The latter step can be applied to fat as well if this is of interest. To study the accuracy of this self-correction approach (see Fig.1(b)) simulations have been performed, using different ΔB_o distributions with different total off-resonance range and spatially differing water/fat fractions.

Experiments were performed on a 1.5T scanner (Achieva, Philips) with a 32-element cardiac coil using forward and reverse 3D stack-of-spirals interleaved abdominal gradient echo imaging (matrix:256², FOV:400×400mm², AQ-window: 15ms, α:10º). Seven volunteers were imaged during a single 24s breath-hold. For the forward spiral, 13 interleaves and TR/TE_1:23ms/1ms were used to measure 45 slices (5mm thickness). For the reverse spiral, 17 interleaves and TR/TE_1:23.5ms/17ms were used to measure 37 slices (5mm thickness). 30% oversampling in the slab direction was applied to compensate for RF pulse imperfections for both methods. Chemical shift encoding was realized by sampling each interleaf three-fold successively in time with a ΔTE of 1.5ms, keeping TR fixed, thus minimizing motion- and flow-related data inconsistencies. Parallel imaging was used to offset the longer scan time of three-point Dixon imaging at least partially permitting single breath-hold 3D studies. But SENSE [8] was applied only in the stack direction (R:2.4). Besides accelerating the acquisition, SENSE as a phase-conservative unfolding approach, reduces the computational complexity by merging all data into one image. DIXON-CPR reconstruction is then performed as a post-processing step using three 3D data sets (see Fig,1). As a result after DIXON-CPR, fat-suppressed 3D data were obtained with weak (TE_{eff}: 2.5ms) and strong (TE_{eff}: 18.5ms) T2* weighting. A simple susceptibility enhanced post-processing, similar to ref. [9], was applied to the water data.

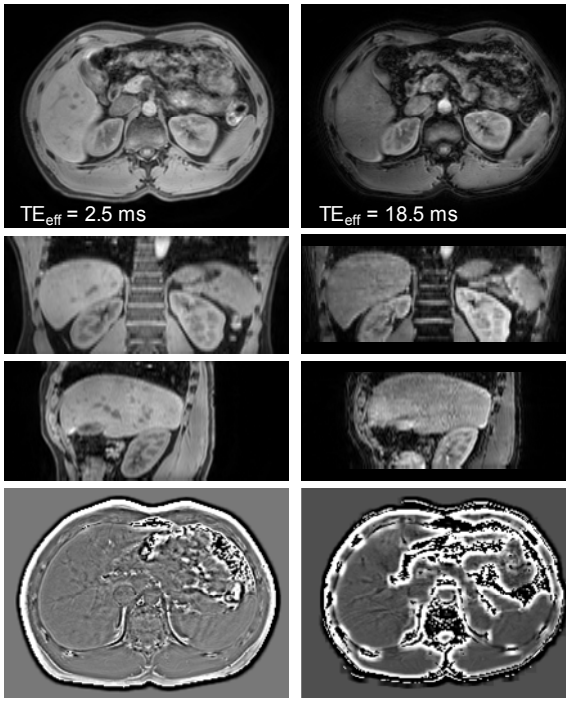

Fig.2. Forward (left) and reverse (right) 3D single breath-hold, Dixon-fat-suppressed spiral (AQ-window:15ms) with different reformats shown. Additionally, post-processed phase maps are presented (difference between unwrapped phase and the 4×4-kernel smoothed unwrapped phase to visualize the stronger local susceptibility effects at higher effective TEs).

Results and Discussion

All volunteer scans were successful and yielded good and reproducible image quality. Excellent fat-suppressed and off-resonance corrected water 3D data were obtained in all scans (see Fig.2). This confirms that efficient high resolution spiral imaging is feasible in the abdomen without extra acquisition of a ΔB_o map commonly used. Thus, a single scan is sufficient to obtain all information for signal separation and correction. The results show that T2* weighting can efficiently be manipulated (from weak to very strong, up to TE_{eff} of 20ms) switching from forward to reverse spiral sampling, enabling a couple of interesting clinical applications. The total ΔB_o inhomogeneity (3D) found among all volunteers was 0.34kHz ± 0.05kHz (standard deviation), but for CPR correction only the maximum variation within each transversal slice is of interest (0.22kHz ± 0.05kHz). Thus, the off-resonance, which DIXON-CPR has to cope with, is in the order of the chemical shift. From the simulations performed, the resulting w/f-separation- and off-resonance correction-error is smaller than 2% (NRMSE), which seems to be acceptable. The combination of spiral signal sampling and DIXON-CPR correction can pave the way for interesting future water-fat resolved imaging applications (including T_2* manipulations). Two-point Dixon, spiral SENSE and compressed sensing could further help to reduce scan time / optimize volume coverage. A merge of forward and reverse spiral sampling in a single scan can be interesting to improve efficiency.

References

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