Spiral Water-Fat Imaging with Integrated Off-Resonance Correction on a Clinical Scanner

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Introduction

Today, water-fat imaging with chemical shift encoding is predominantly performed with multi-echo sequences that sample a single line in k-space twice or thrice after an excitation. These sequences limit the total duration of data acquisition within a repetition time to a few milliseconds. Higher scan efficiency may be attained by covering more than a straight line after an excitation, for instance a spiral arm. While strong susceptibility to off-resonance effects is introduced in this way, water-fat imaging with chemical shift encoding involves a mapping of the field inhomogeneity, resolved into contributions from the main field and chemical shift, anyway, rendering it ideally suited for an efficient off-resonance correction. In this work, a fully automated and integrated reconstruction, separation, and correction for spiral water-fat imaging is implemented on a clinical scanner and evaluated in abdominal and cardiac imaging.

Methods

Given the constraints on processing times in clinical applications, the sequential approach illustrated in Fig. 1 was pursued to approximate a non-linear inversion of the signal model for spiral water-fat imaging [1]. The acquired data are first transformed to image space and combined to single-echo images (TE_1-TE_3) using precalibrated coil sensitivity maps to support parallel imaging, to preserve phases, and to achieve compression. Generalized Dixon methods [2,3] then serve the estimation of blurred water and fat images and of a field map (W′, F′, ΔB_0). A gridding-based conjugate phase reconstructions [4] is finally employed to obtain corrected water and fat images (W, F).

The sequential reconstruction, separation, and correction were implemented on a clinical 1.5 T scanner (Philips Healthcare, Best, The Netherlands) by modifying and extending its software. Abdominal and cardiac imaging were performed with 16- and 32-element receive coils, respectively. 3D gradient-echo sequences with chemical shift encoding were employed to sample k-space on a stack of interleaved spiral trajectories, which were shifted in time to collect data at two or three echo times with 1.5 ms spacing. The abdominal protocol typically imaged a FOV of 380 x 380 x 225 mm^3 with a resolution of 1.5 x 1.5 x 5 mm^3 in 8 s per echo time during breath-holding [5]. The cardiac protocol included an outer volume suppression, permitting a FOV of 256 x 256 x 150 mm^3 for whole-heart coverage, and provided a resolution of 1.3 x 1.3 x 3 mm^3 in about 3 min per echo time during free breathing, using navigator gating with an assumed efficiency of 50% [6].

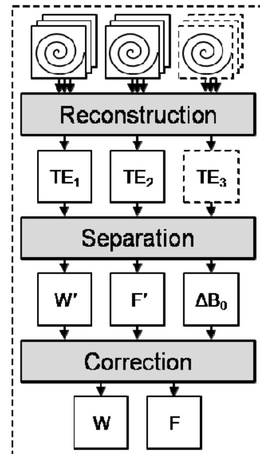

Fig. 1. Flow chart of the sequential single-echo image reconstruction, water-fat separation, and off-resonance correction, as it was implemented on a clinical scanner.

Results

The implemented processing is illustrated on a selected slice from one of the abdominal scans in Fig. 2. Despite high off-resonance frequencies ranging from -400 Hz to +100 Hz in this example, which especially lead to a strongly blurred fat image, good overall image quality is achieved after the correction. The results obtained with the cardiac scans are exemplified in Fig. 3. While some aliasing remains, the main coronary arteries are well depicted, with particularly high contrast in the fat images. The reconstruction, separation, and correction took for both protocols about 35 s overall. Approximately one third was spend on each of the three tasks.

Conclusions

Using a sequential approach to reconstruction, separation, and correction, spiral water-fat imaging is feasible on clinical scanners with good image quality and acceptable processing times. Compared to conventional water-fat imaging, only about 10 s are additionally needed for the correction, which remains effective as long as the main field varies smoothly within the support of the blurring point-spread function. Thus, the way is paved for a thorough evaluation of spiral water-fat imaging in clinical applications.

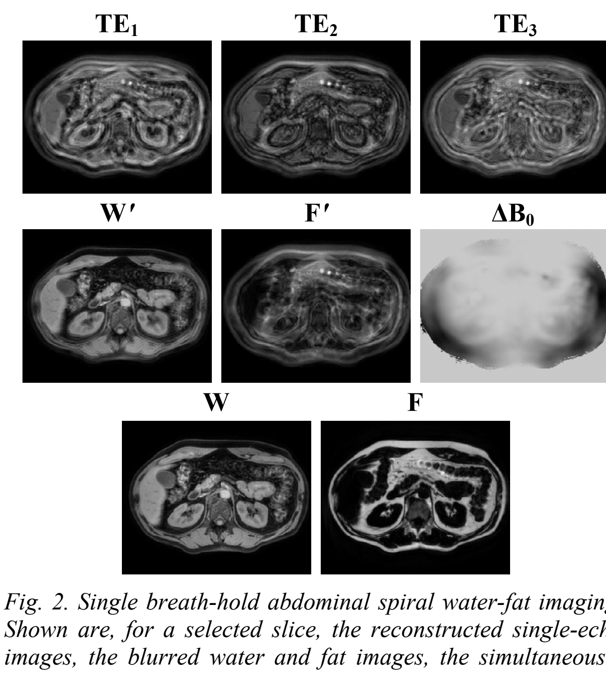

Fig. 2. Single breath-hold abdominal spiral water-fat imaging. Shown are, for a selected slice, the reconstructed single-echo images, the blurred water and fat images, the simultaneously estimated field map, and the corrected water and fat images.

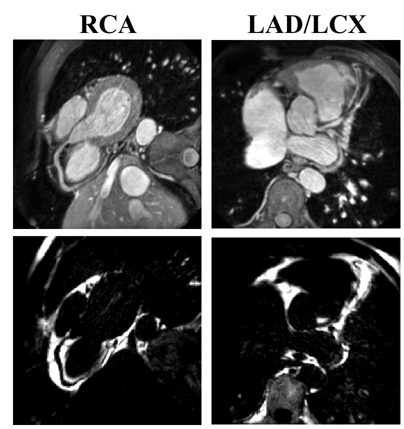

Fig. 3. Free breathing whole-heart spiral water-fat imaging. Shown are reformats of the corrected water (top) and fat (bottom) images, targeted at the right coronary artery (RCA) and the left anterior descending and the left circumflex artery (LAD/ LCX).

References

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