Off-Resonance Correction in PROPELLER using Dixon Water-Fat Separation

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Purpose

Periodically rotated overlapping parallel lines with enhanced reconstruction (PROPELLER) involves a hybrid Cartesian-radial k-space sampling, which allows correcting motion between the Cartesian sub-acquisitions called blades in reconstruction[1]. The correction is usually limited to in-plane rigid-body motion, but artifacts from other motion are reduced as well even without correction due to averaging in the central k-space, similar to radial k-space sampling. Recently, PROPELLER has been combined with Dixon methods to render water-fat imaging motion insensitive[2,3]. For this purpose, turbo spin-echo (TSE) sequences were extended to acquire multiple gradient echoes after each refocusing pulse, and separate images were reconstructed from each gradient echo prior to the water-fat separation. However, like parallel imaging, which is preferably applied to individual blades to improve the motion estimation and to decouple the unfolding[4], the water-fat separation may be performed on single blades instead. In this work, this approach is demonstrated to be feasible and to facilitate an off-resonance correction for image quality enhancement.

Methods

To maximize data consistency for the water-fat separation, the modified TSE sequence illustrated in Fig. 1 is proposed. It acquires a single blade twice in a single echo train, once without and once with an echo shift. Corresponding chemical shift-encoded k-space data are collected after subsequent refocusing pulses, using a unipolar readout gradient to avoid eddy current-induced phase errors. Parallel imaging is applied to widen the blade and to combine the data from different receive coils[5]. As shown in Fig. 2, a first water-fat separation is then performed in image space to estimate the underlying main field inhomogeneity[6]. The resulting phase offset in the blade acquired with an echo shift is compensated. Moreover, the arising spatial distortion is corrected by gridding from the non-uniformly sampled image space to a uniformly sampled k-space. A second water-fat separation is finally carried out in k-space, which ignores main field inhomogeneity, but considers the chemical shift of the individual resonances in the fat spectrum to eliminate the corresponding spatial shift[7]. Only then, the PROPELLER reconstruction, as described elsewhere[8], is applied to the water and fat k-space data from all blades.

This approach was explored in abdominal T_2-weighted TSE imaging on volunteers during breath-holding, using a 3 T Ingenia scanner (Philips Healthcare, Best, The Netherlands).

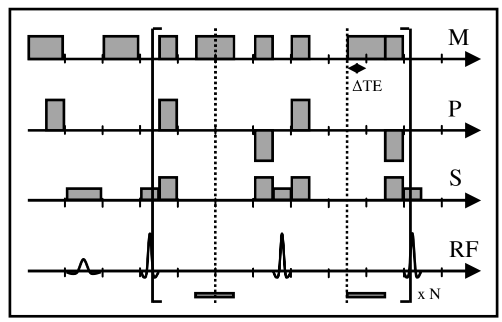

Fig. 1. Schematic sequence diagram of the employed interleaved turbo spin-echo acquisition.

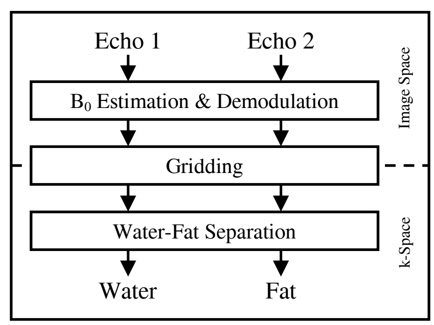

Fig. 2. Flow chart of the off-resonance correction and water-fat separation performed on single blades.

Results

The successful separation of water and fat in a single blade is demonstrated in Fig. 3. The water and fat images obtained after the proposed separation, correction, and combination of all blades from the same acquisition are shown in Fig. 4. Compared with the water and fat images resulting from a separation after the PROPELLER reconstruction, the compensated fat shift is most striking, whereas the reduced blurring due to the main field inhomogeneity correction is rather subtle in this case.

Discussion

To take advantage of the Cartesian k-space sampling in single blades for an off-resonance correction, the water-fat separation has to be performed before the PROPELLER reconstruction. Although its feasibility is shown in this work, such a separation tends to be less robust, mainly because of highly anisotropic voxels and lack of a through-slice reference. A thorough comparison in this respect with more complex off-resonance correction algorithms for non-Cartesian k-space sampling remains to be done. However, such a separation also promises to render the motion correction more accurate and thus may become the preferred approach to integrating Dixon methods into PROPELLER.

References

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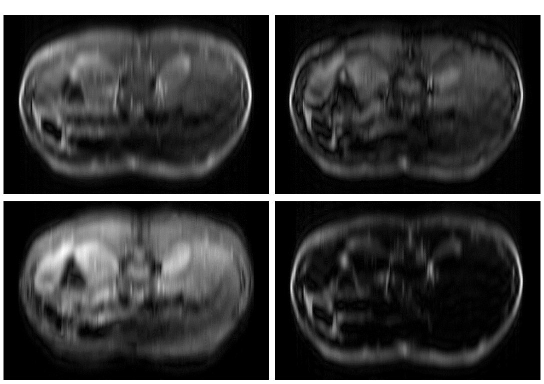

Fig. 3. Zero-filled source images from one blade (top), acquired without and with echo shift in a single shot, and water and fat images produced from them (bottom).

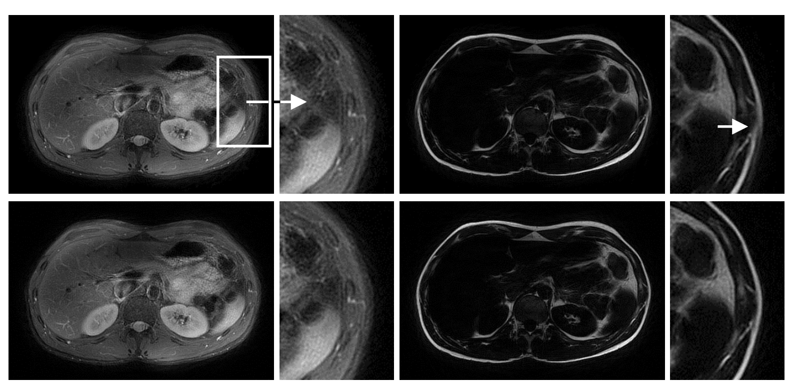

Fig. 4. Water and fat images resulting from a separation after (top) and before (bottom) the PROPELLER reconstruction. The arrow on the right highlights a fat shift artifact removed by the described approach.