Water-fat separation with IDEAL, undersampled radial acquisition, and off-resonance deblurring

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Introduction
Multipoint water-fat separation method [1,2] achieves uniform water and fat separation with reduced sensitivity to B_0 and B_1 inhomogeneities. Recently, IDEAL (Iterative Decomposition of water and fat with Echo Asymmetry and Least Square estimation) [3,4] has drawn considerable attention because it achieves optimal signal-to-noise performance across all water/fat ratios. However, scan time is prolonged due to the three-echo acquisition. Here, we combine IDEAL with radial acquisition to exploit the advantage of radial acquisition, which allows for undersampling with milder artifacts compared to Cartesian sampling [5]. By alternating the spokes for each echo time, the point spread function can be controlled to produce even milder artifacts. Thus, with the radial approach, it is possible to accelerate by an arbitrary factor simply by changing the number of spokes. However, a downside to radial acquisition is the sensitivity to off-resonance effects, which lead to blurring artifacts. In this work, we combined undersampling radial IDEAL acquisition with deblurring, which can be achieved by multifrequency reconstruction, or by simple off-resonance phase correction (for mild B_0 inhomogeneity) to achieve time efficient water-fat imaging at arbitrary acceleration, which is limited only by the signal-to-noise ratio and undersampling artifacts.

Methods
An IDEAL FLASH (Fast Low Angle SHot) radial acquisition pulse sequence was implemented on a Bruker 7T Biospec system (Bruker BioSpin, Ettlingen, Germany). Three IDEAL-optimal echo times were acquired alternatively on each radial spoke (Fig.1). After acquisition, data were phase corrected, gridded, and Fourier reconstructed for each echo time. Then, the IDEAL algorithm was applied to achieve water and fat separation. Simple off-resonance phase correction was performed on the fat image to reduce blurring caused by chemical shift. All reconstructions were performed in Matlab (The Mathworks, Natick, MA). Phantom data were acquired at echo times of 3.346, 3.673, and 3.999 ms, repetition time = 50 ms, field of view is 35 mm x 35 mm. *In vivo* data were acquired from the lower abdomen of a mouse with the same parameters and with respiration gating.

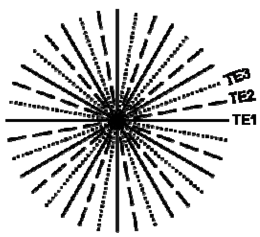

Fig. 1 Radial IDEAL acquisition k space

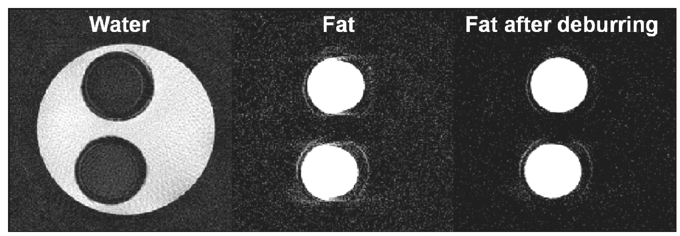

Fig. 2 Water fat separation, and deblurred fat images of phantom

Results
Fig. 2 shows the water, fat, deblurred fat images from the phantom data, showing robust water and fat separation with 33% k-space sampling. The deblurred fat image is shown on the right.
Fig. 3 shows the *in vivo* data acquired with different numbers of radial spokes. Comparing 33% with 100% data sampling, acquisition is accelerated 3 time without significant loss of water-fat separation performance. It only affects the signal-to-noise ratio and residual undersampling artifacts.

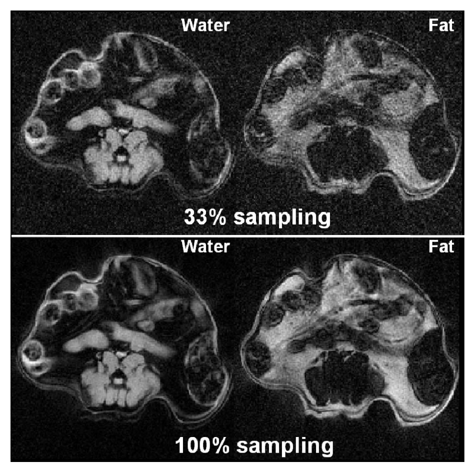

Fig. 3 In vivo comparison IDEAL performance of 33% sampling v.s. 100% sampling in radial *k*-space

Discussion
In this work, we combined radial acquisition with IDEAL water and fat separation. We show that the undersampled radial acquisition is able to arbitrarily accelerate without affecting IDEAL water-fat separation performance. We show that with 3-fold acceleration, the *in vivo* data still have acceptable image quality. In addition, when B_0 inhomogeneity is not severe, simple deblurring by phase correction in *k*-space can be applied to the off-resonance chemical species, fat here, to reduce chemical shift artifacts for radial acquisition. However, multifrequency reconstruction will be needed in case of severe B_0 inhomogeneity.

References
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