Joint Water-fat Separation and Deblurring with Spiral In-out Sampling
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Introduction
Spiral imaging with in-out trajectories is efficient for spin echo and $T_2^*$ weighted sequences. Two images can be reconstructed from the spiral-in and spiral-out parts respectively. These two images can then be combined to increase signal to noise ratio or utilized to extract new information. Based on previous work in [1], we propose an iterative approach to simultaneously separate and deblur water and fat using these images.

Theory
Similar to the notation in [1], the blurring is formulated as
\[
\tilde{B}^H \tilde{g} = \tilde{B}^H \tilde{f},
\]
where $\tilde{g} = [g_{in}, g_{out}]$ are the collected images, $\tilde{B} = [B_{inw}, B_{outw}, B_{inf}, B_{outf}]$ represents the blurring process, $\tilde{f} = [f_{water}, f_{fat}]$ are the water and fat images. $H$ denotes the conjugate transpose. $\tilde{B}$ is calculated from a known field map of $B_0$ inhomogeneity. Eq. 1 is solved by a conjugate gradient approach [1]. The ‘blur’ and the ‘deblur’ processes are implemented by spatially varying convolutions.

Methods
A schematic plot of the spiral in-out readout waveform is shown in Fig.1 (a). A short duration is inserted between the spiral-in and the spiral-out parts for better water-fat separation. The time delay between the sampling points of spiral-in and spiral-out parts that are at the same k-space location varies as the k-space radius changes. As a result, different spatial frequencies converge at different rates, which can cause ringing artifacts. If water and fat are both real at time $t=0$, with a minor modification as $\tilde{g} = [g_{in}^*, g_{out}]^T$, the problem can be seen as an analogy to the echo shifted spiral-out sampling (Fig.1 (b)). To implement this modified approach, we assume that water and fat are in phase at time 0. A slowly varying phase map is estimated from $\tilde{f}$ computed without the water-fat in-phase constraint. This phase is eliminated from $\tilde{g}$. $\tilde{f}$ is then recalculated with the water-fat in-phase constraint.

Results and Discussion
We tested the proposed approach with data of a canola oil-water phantom and in-vivo data acquired on a 3T Philips Ingenia scanner. The duration between the spiral-in and the spiral-out parts was 0.7 ms. The phantom data were collected with gradient echo stack of spirals (SOS). The data were corrected for $B_0$ eddy currents before reconstruction [2]. The in-vivo experiment was performed using a turbo spin echo SOS sequence. In both experiments, a field map was obtained [3] from a separate gradient echo SOS data set. The time for the iterative approach was around 1-2 min per coil. We can see the ringing artifacts along sharp boundaries of the water and fat images (Fig.2 (c-d) and Fig.3 (c)). The water-fat in-phase constraint removed these artifacts (Fig. 3 (e)).

Acknowledgement
This work was funded by Philips Healthcare.

References