Water-Fat Separation with a Bipolar Multiecho 3D Concentric Cylinders Trajectory

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Introduction: For water-fat separation using Dixon techniques [1,2], a bipolar multi-echo sequence acquires data more efficiently than a comparable unipolar multi-echo sequence, and also enables more robust field map estimation by shortening echo-spacings, which is crucial for reliable water-fat separation [3]. In this work, a variation of the bipolar multiecho sequence was implemented with a 3D concentric cylinders trajectory [4-6]. The concentric cylinders sequence requires fewer excitations than a comparable 3DFT sequence, thereby enabling a further scan time reduction while maintaining robustness to off-resonance effects.

Methods: Bipolar Multi-echo Sequence with 3D Concentric Cylinders: One of the main post-processing steps of a bipolar multi-echo sequence is to correct the k-space echo misalignment due to gradient delays and eddy currents, which can be corrected by acquiring a set of baseline reference scans [7,8]. On top of that, the 3D concentric cylinders version of bipolar multi-echo sequences (Fig. 1a) needs to address the effects of oscillating G_x and G_y gradients during the bipolar readout. Considering that the main effect of delays in sinusoidal G_x and G_y waveforms is a rotation in k_x-k_y plane [9], which in turn results in the same amount of rotation in the image domain, the step of correcting the linear phase in the image domain caused by the k-space echo misalignment can be performed independently of the rotation correction. Because the rotation occurs in the same direction for the three bipolar echoes (Fig. 1b) and G_x, G_y waveforms are smoothly oscillating, the amount of rotation differences may not be noticeable when the delays are not severe. After these two steps, the generalized k-space decomposition with chemical shift correction [10] scheme was used to generate water and fat images.

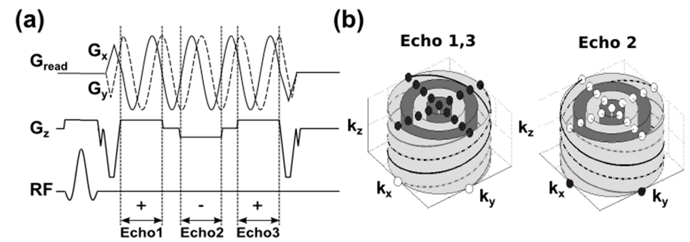

Fig. 1. (a) Pulse sequence timing diagram. Three one-revolution (N_{rev} = 1) bipolar echoes are acquired during four revolutions of G_x, G_y gradients. **(b)** 3D concentric cylinders trajectories for the 1st and 3rd, (left) and the 2nd echoes (right). For each trajectory, five cylinders including the innermost cylinder with radius zero are depicted. Black/white dots indicate where helical interleaves (only shown on the side of each outermost cylinder) start/end, respectively.

Imaging Parameters: To demonstrate the feasibility of water-fat separation using bipolar multiecho sequence with 3D concentric cylinders, both phantom and in vivo experiments were performed on a GE Excite 1.5 T scanner with an extremity coil. Gradients for the 3D concentric cylinders trajectory were designed to provide isotropic resolution = 1 mm and FOV = 17×17×13 cm^3 (matrix size = 168×168×128). Both SPGR and SSFP sequences were implemented. For SPGR, TE = 3.3/5.5/7.7 ms, TR = 20 ms, and flip angle = 30°. For SSFP, TE = 2.8/5.6/8.4 ms, TR = 12 ms, and flip angle = 60°.

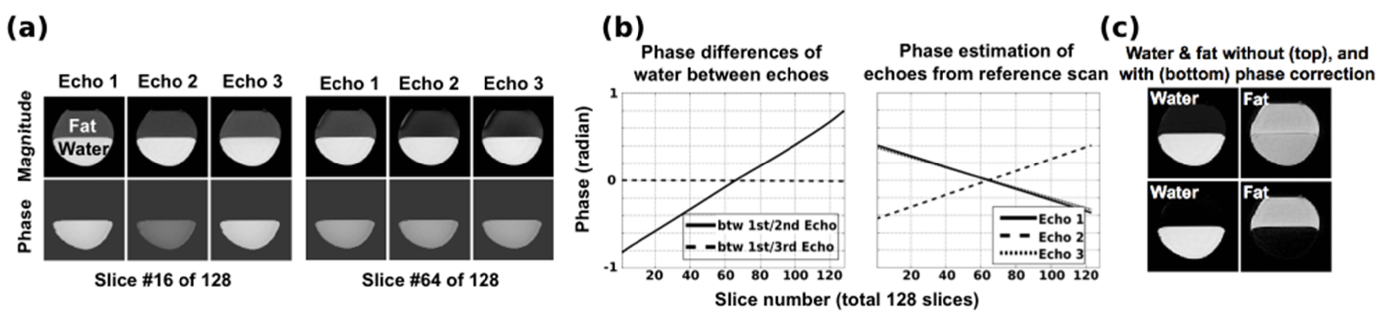

Fig. 2. Axial phantom results (SSFP). **(a)** Two axial slices of a water/fat phantom. Unlike in the center slice (right), a phase difference between the odd and even echoes was significant in the off-center slice (left). **(b)** Phase difference of water signal between echoes after field inhomogeneity correction (left), and phase estimations of three echoes from a set of reference scans (right). The measured differences and the estimated phases were well-matched. **(c)** Water and fat images of slice #16 without/with phase correction. The remnant fat signal in the water image, and the remnant water signal in the fat image were reduced by factors of 3 and 10, respectively.

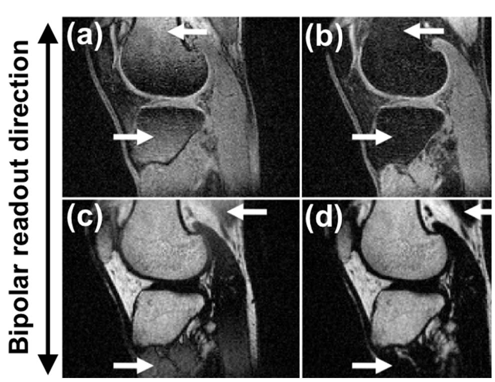

Fig. 3. Sagittal image of the knee (SPGR). **(a)** Water image without phase correction. **(b)** Water image with phase correction. **(c)** Fat image without phase correction. **(d)** Fat image with phase correction. Arrows indicate regions with significant improvement in water-fat separation.

Results: Phantom results in Fig. 2 verify that the same linear phase correction scheme in the bipolar readout direction using a set of baseline reference scans (Fig. 2a, 2b) can be effectively applied to the concentric cylinders version of the bipolar multiecho sequence, and the water-fat separation in the off-center slice is significantly improved (Fig. 2c). *In vivo* results in Fig. 3 also show the improvement of water-fat separation around the knee with phase correction, especially for off-center slices in the bipolar readout direction.

Discussion: We have demonstrated the feasibility of implementing the bipolar multiecho sequence with the 3D concentric cylinders. With a factor of $2N_{rev}$ fewer excitations than a comparable 3DFT acquisition [4-6], this centric-ordered 3D trajectory version of bipolar multiecho sequence can be efficiently applied to any magnetization-prepared imaging.

References: [1] Dixon, Radiology 153:189, 1984. [2] Glover, MRM 18:371, 1991. [3] Lu, ISMRM, p.1638, 2007. [4] Mugler, SMR, p.483, 1995. [5] Ruppert, ISMRM, p.208, 2003. [6] Kwon, ISMRM, p.4973, 2010. [7] Lu, MRM 60:198, 2008. [8] Ma, MRM 52:415, 2004. [9] Wu, MRM 63:1210, 2010. [10] Brodsky, MRM 59:1151, 2008.