k-Space Shift Correction Using an Alternating Gradient Readout Acquisition for Improved Radial Fat-Water MRI

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Introduction: A primary challenge associated with the sampling trajectory of radial MRI is the imperfect alignment of each sampled diagonal with the center of k-space. Gradient imperfections and timing delay errors cause the sampled trajectory to shift from the intended trajectory [1]. The shift changes as readout direction is rotated. Methods exist to align miscentered k-space samples for alternating radial [2] or PROPELLER readouts to the center of k-space by comparing neighboring radial lines (or blades) that have nearly opposite readout direction. The opposite readout direction causes the shift to be in opposite directions. According to the Fourier Shift Theorem, the k-space shift can be found from the phase difference between spatial domain projection data acquired with opposite readout direction. In this work, an alternating readout direction phase correction algorithm for radial MRI is tested on a conventional single gradient echo acquisition and a multiple fast field echo (mFFE) acquisition used for fat-water imaging.

Materials and Methods: MRI data of phantoms were obtained using a one-channel TR head coil and a radial sampling scheme of 256 projections equally spaced over 180°. The data were acquired on a 3T Achieva scanner (Philips Healthcare, Best, The Netherlands) with alternating frequency encode (readout) direction as depicted in Figure 1. Two phantoms, a picture image quality test (PIQT) phantom and a fat-water phantom (a bottle containing half peanut oil and half tap water) were used to evaluate the algorithm's performance. The correction algorithm finds the spatial domain phase difference between a single radial line and the average of its closest neighbors, which were acquired with an opposite readout direction. Only a central section of the phase difference (within the object) is considered for phase unwrapping and linear fitting with a magnitude weighted least squares fit. After detected k-space shifts along the frequency encode direction were removed, the fat-water separation was performed in k-space with both field inhomogeneity and chemical shift k-space phase accrual considered [3]. After separation into fat and water k-spaces, the NUFFT toolbox was used for non-Cartesian reconstruction [4].

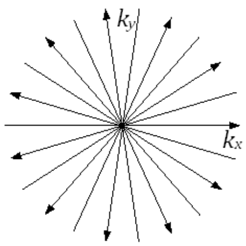

Figure 1. Alternating readout radial sampling scheme.

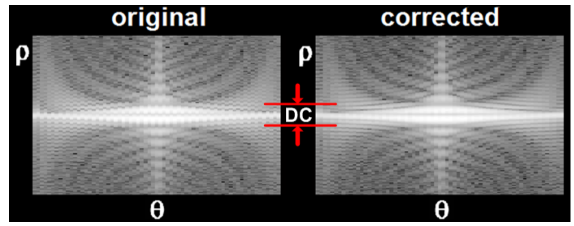

Figure 2. Radial k-space data of peanut oil: before (left) and after (right) alternating readout correction.

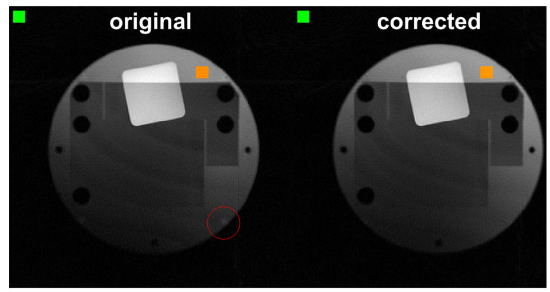

Figure 3. Improvement is observable in the area of the red circle (left) where the white spot artifact is removed after correction (right).

Figure 4. Fat signal fraction; Signal highlighted by yellow and noise by green; Fat signal percentage improvement is noticeable within red box.

Results: Figure 2 compares radial k-space data before (left) and after (right) correction. Improvement is clear near DC where the saw tooth pattern is removed. Figure 3 displays the PIQT phantom reconstructed from uncorrected (left) and corrected k-space data (right). The improvement is observable within the red highlighted circle in which the white spot artifact disappears. SNR (calculated using signal from orange ROI over noise from green ROI) improved from 58.2 to 58.5. Figure 4 shows the correction performance of the approach for a fat water imaging fat signal fraction map. Fat signal fraction is nearly 100% in the area of the peanut oil, but artifact is observable on the left panel in the area boxed in red where the signal decreases to an unreasonable level. The same area on the right panel exhibits a more realistic level of fat signal fraction. SNR defined as signal from the yellow ROI to noise in the green ROI improves from 0.55 to 0.60.

Conclusion: Correction of k-space trajectory shifts in radial MRI using an alternating readout direction acquisition and a post-processing algorithm to detect and remove the shifts improves radial MRI reconstruction quality in both standard gradient echo imaging and multi-echo gradient echo fat-water imaging.

References: 1. Peters DC et al. Magn Reson Med (2003) 50(1):1-6. 2. Li Z et al. Magn Reson Med (2009) 61(6): 1415–1424. 3. Ethan Brodsky et al. Magn Reson Med (2008) 59:1151-1164 4. Fessler JA et al. IEEE Trans on Sig Proc (2003) 51(2): 560-574