Target Audience – Researchers working with radial trajectories.

Purpose – Radial acquisition of k-space is becoming a highly important acquisition strategy for robust dynamic imaging and real-time MRI. In contrast to Cartesian readout of k-space, gradient delays and timing errors have to be precisely corrected in order to avoid artifacts in the reconstructed images. Delay induced shifts of the acquired radial data along the readout directions can cause especially severe signal drop outs and smearing artifacts in the reconstructed images. Although research has been performed on correcting these errors, most solutions require either additional hardware for monitoring the true gradient trajectory during data acquisition or additional calibration or template measurements, which often work only for a particular set of acquisition parameters or homogeneous phantoms. In this work we introduce a method to correct shifts of the data along the readout direction without performing any additional measurements.

Methods – Phantom and in vivo volunteer measurements were performed on a clinical 3 T system (TIM Trio, Siemens Healthcare) using a radial 2D FLASH sequence with the following parameters: acquisition matrix 144 x 144, FOV = 220 x 220 mm², TR = 5.30 ms, TE = 2.76 ms, flip angle FA = 8° (phantom data) and FA = 10° (in vivo data), number of radial readouts N = 233, acquisition bandwidth BW = 102.04 kHz. Readout polarity of every other spoke was inverted to obtain opposing delay effects evenly distributed at the center of k-space (Fig. 1). During image reconstruction acquired raw data were shifted along the readout direction with 80 linearly spaced shifts Δr in the range from -4 to 4 readout points. This was implemented using the Fourier Shift Theorem to achieve sub dwell time accuracy. For each readout shift we reconstructed the image using 2D-gridding and iterative grid weights estimation followed by a 2D-FFT. The optimal shift Δropt yielding images free of delay artifacts was obtained by analyzing the magnitude of all data voxels. For this purpose the sum over the magnitude of all data voxels I_sum was calculated as a function of Δr. The optimal shift Δropt was then estimated from the local maximum of I_sum(Δr).

Results – The sum over the magnitude of all data voxels as a function of Δr is shown in Figure 2 for both the phantom (2a) and the in vivo (2b) measurement. Optimal shifts Δropt were 1.3 and 1.1 readout points (corresponding to 6.37 μs and 5.39 μs time delay) for the phantom and in vivo data, respectively. The results were obtained for different slices with different object structures. Even in slices with low overall signal intensity (slice 1, phantom data) the optimal shift was successfully determined. Uncorrected radial readouts resulted in images that were highly degraded by artifacts, whereas correction with the identified optimal shift yielded highly improved, artifact free images (Fig. 3).

Discussion & Conclusion – The presented method was implemented fully automated without further user interaction. It proved to be reliable for correcting the radial shifts along readout direction in phantom and in vivo measurements. Since an image has to be reconstructed for each modulated shift computation time can be optimized by undersampling input data or by applying fewer shift values and fitting an appropriate function to the resulting curve. For reconstruction of larger data sets it should be sufficient to perform the described modulation and analysis for data of a single slice, since readout shifts are supposed to remain constant throughout the measurement.