Filtered backprojection, regridding, and POCS correction in projection reconstruction

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Introduction: There has been renewed interest in radial/projection acquisitions due to their relative insensitivity to patient motion and their suitability for fast imaging. However, gradient delays can result in shifts and phase offsets between views, leading to a miscentering of k-space trajectories, which then give rise to reconstruction streak artefacts [1]. A number of solutions have been proposed, including adjustment of gradients [1], magnitude-only filtered backprojection (mFBP) [2], measurement of the trajectory [3], and use of near anti-parallel projections for phase estimation [4]. The aim of this work is to examine when mFBP might be effective and to use a projections onto convex sets (POCS) algorithm [5] to provide image-based correction where mFBP is ineffective.

Methods: We imaged human subjects on a 1.5T scanner, using radial acquisitions [6] with angular coverage of 180°. A short echo acquisition (TE = 4 ms) of a single slice was used to give an image with little off-resonance and therefore of uniform phase. A longer echo acquisition (TE = 26 ms) gave an image with significant non-uniform phase. To simulate the effect of time-delays, the data were shifted with random shifts of up to ±2 time points and multiplied with a random phase. This gives the projection data a zeroth and first-order phase shift before reconstruction. The POCS algorithm involved iterating the following steps: (i) reconstructing the corrupted image (ii) masking signal outside the parent image to zero (iii) inverse transforming the masked image to give a "model k-space" and (iv) linear phase correcting the corrupted data to match the phase of the data in the model k-space, ie using the model k-space as a "reference scan". Iterations were stopped when the average shift correction was < 0.15 data points.

Results and Discussion: Fig 1 show the reconstructed short TE data with mFBP (Fig 1a) and regridding (Fig 1b and c). Both methods are equally effective because the phase of the image is uniform (Fig 1d). Fig 2 show the short TE data after simulated miscentering, reconstructed with (a) mFBP which is effective as expected from the Fourier shift theorem, which states that the magnitude projections are unaffected by shifts and phase offsets. However, regridding results in artefacts (Fig 2b), but this is corrected by the POCS algorithm after 31 iterations (Fig 2c). Brightened images show reduction in streak artefacts in Fig 2d compared with Fig 1c.

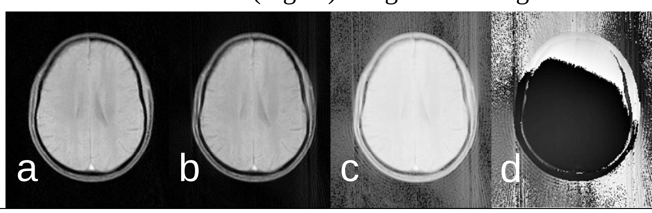

Fig 1 Uniform phase object reconstructed with (a) mFBP (b) regridding (c) regridding brightened (d) phase of regridded image.

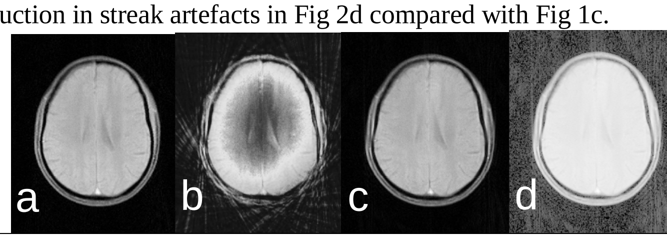

Fig 2 Uniform phase object after simulated miscentering, reconstructed with (a) mFBP (b) regridding (c) POCS regridding (d) POCS regridded image brightened.

Where off-resonance with long TE results in non-uniform phase (Fig 3d), mFBP is ineffective and leads to increased artefacts in regions of non-uniform phase (Fig 3a) because a magnitude projection no longer properly describes a complex object. With phased regridding (Fig 3b and c) the artefacts are not so pronounced. With simulated miscentering, reconstruction with mFBP was unchanged as expected (identical with Fig 3a), but artefacts appear with regridding (Fig 4a), which is corrected by POCS after 13 iterations (Fig 4b and c). There is a small reduction in streak artefacts in Fig 4c compared with Fig 3c. The phase after POCS correction is shown in Fig 4d showing similar uniformity with Fig 3d.

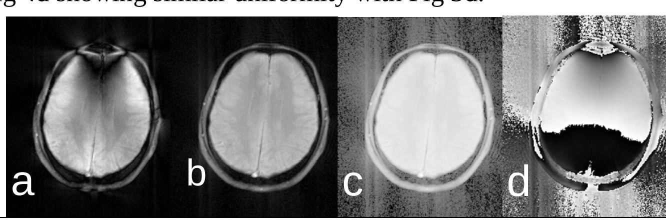

Fig 3 Non-uniform phase object reconstructed with (a) mFBP (b) regridding (c) regridded image brightened (d) phase of image after regridding.

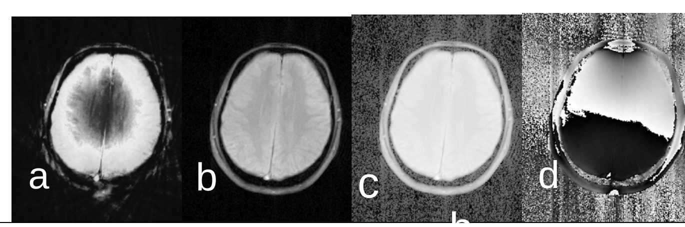

Fig 4 Non-uniform phase object after simulated miscentering, reconstructed with (a) regridding (b) POCS regridding (c) POCS regridded brightened (d) phase of object after POCS regridding.

Conclusion: If the object has spatially *uniform* phase then mFBP is effective even with linear phase factors which may be caused by delays or movement. With phased regridding, although linear phase factors result in artefacts, this may be corrected by a post-processing, image-based POCS algorithm. If the object has spatially *non-uniform* phase, mFBP enhances artefacts and phased reconstruction is necessary. If miscentering due to linear phase factors are present, then this can be corrected with the POCS algorithm.

References: [1] Peters DC et al, MRM 2003;50:1-6. [2] Trouard TP et al, MRM 1999;42:11-18. [3] Dale B & Duerk JL, ISMRM 2002, 2334. [4] Rasche V et al, MRM 1999;42:324-334. [5] Lee KJ et al, MRM 2002;47:812-817. [6] Wild JM et al, MRM 2003;49(6):991-7.