PROPELLER-EPI-DWI with oblique N/2 ghost correction using 2D linear phase correction and interlaced Fourier transform reconstruction

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Introduction: The PROPELLER-EPI (periodically rotated overlapping parallel lines with enhanced reconstruction using EPI as signal readout) has been shown useful for diffusion applications with reduced geometric distortion [1]. PROPELLER-EPI consists of EPI signal readout with alternative echoes, with the phase inconsistencies between odd and even echoes generating oblique N/2 ghost artifact [2] in each rotating blade, as in conventional oblique EPI imaging. A 2D phase correction with double-FOV reference image can be applied for oblique ghost reduction in each blade prior to PROPELLER-EPI reconstruction [3,4]. This 2D phase correction consists of fitting a 2D phase error map for correction. In this work, we demonstrate the feasibility of an alternative method without the need for 2D fitting and determination of 2D margin, using double-FOV reference to estimate linear phase along two dimensions, and then combined with interlaced Fourier transform (FT) [5] to reduce the oblique N/2 ghost.

Material and method: In the original 2D phase correction method [3], the 2D phase difference map between odd and even samplings can be measured using a double-FOV reference image. In our proposed approach, the double-FOV reference image without overlapping between ghost and object was used to provide estimations of linear phase errors along kx and ky, and the interlaced sampling interval along ky after zeroing out the ghost. The linear phase errors along kx and ky are caused respectively by echo shift along kx and interlaced sampling along ky between odd and even samplings. Thus the flowchart of our proposed correction method is as shown in Fig.1. Three correction parameters (kx and ky linear phase error, and interlaced sampling interval along ky) were first calculated from double-FOV reference image with b=0, and then the correction was applied to all rotating blades with and without diffusion gradient. Phantom images were acquired using PROPELLER-EPI-DWI technique at 1.5T (Signa HDxt, GE): FOV 17x17cm, blade size 32*128 (ETL=32), rotating angle 15°, NEX 1, TE 76.8ms, TR 4000ms, 5mm slices without gap, 12 blades for 180° k-space coverage, b-values 0 and 300 s/mm2. The b=0 double-FOV reference scan was acquired for each blade with half area of phase gradient. Both 2D phase correction and our method were applied to the same data for comparison.

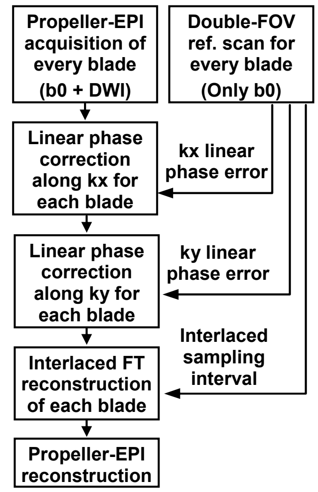

Fig.1 Flowchart of oblique N/2 ghost correction with linear phase corrections and interlaced FT.

Results: Low-resolution single blade images containing fine structural details of the phantom are shown in fig.2 with 2D phase correction (black box) and proposed correction method (gray box). A set of rotating blades data and corresponding PROPELLER-EPI reconstructed images with 2D phase correction (black box) and proposed correction method (gray box) are shown in fig.3.

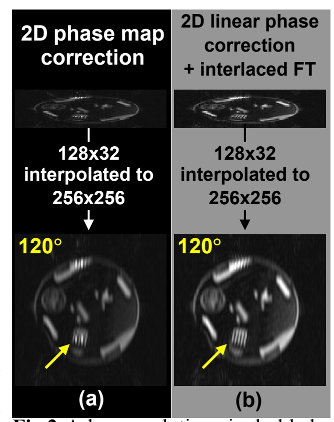

Fig.2 A low-resolution single blade image (120° rotating angle) with (a) 2D phase correction versus (b) correction method with framework proposed in Fig.1.

Discussion & Conclusion: The estimation and fitting of 2D phase map is challenging for low-resolution image, especially when there exist fine structural details. In addition, any morphological difference between the low-resolution double-FOV reference and original image could reduce the correction efficacy using the estimated 2D phase map. Thus, applying 2D phase correction to low-resolution blade image might encounter imperfect correction at the structural details (yellow arrows in fig.2a), resulting in blurring effects on the PROPELLER-EPI image (fig.3b). Artifacts are also seen in background region (white arrows in fig.3c) due to imperfect correction of some blades. In contrast, our proposed correction method is less sensitive to reduced resolution in the double-FOV reference (yellow arrows in fig.2b). Consequently, the blurring effect at the structural details is reduced in the PROPELLER-EPI reconstructed image (fig.3e). Minor inaccuracy of 2D phase map estimation for low-resolution blade images also induces imperfect correction in several blades (yellows arrows in fig.3a), which is less prominent in the corresponding blade corrected using our proposed method (fig.3d). But these minor effects lead to no visual difference in the final PROPELLER-EPI-reconstructed images (figs.3c & 3f), likely due to reduced signal energy spread to different directions with PROPELLER reconstruction. In conclusion, our proposed method for reducing oblique N/2 ghost correction presents an alternative way to utilize the double-FOV reference data. Its insensitivity to very low-resolution double-FOV reference is particularly suitable for RPOPELLER-EPI where low-resolution blades are combined to reconstruct high-resolution images.

Reference: [1] Wang FN, et al, MRM, 54:1232 (2005). [2] Bruder H, et al, MRM, 21:311 (1992). [3] Xu D, et al, MRM, (2000). [4] Chang HC, et al, ISMRM 2010 #4893.[5] Ronald NB, McGraw-Hill, 2000.

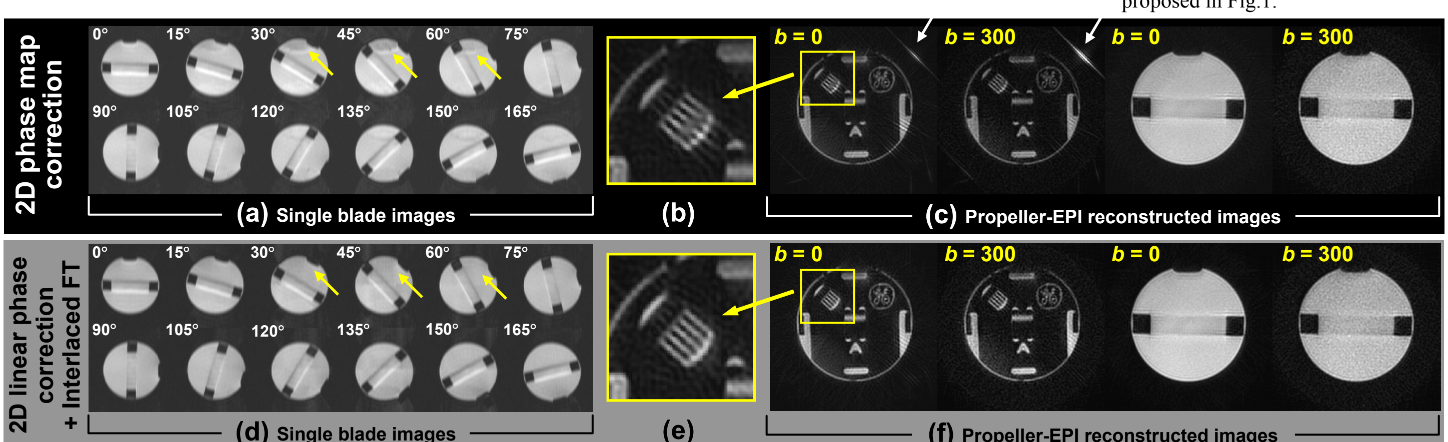

Fig.3 The same set of rotating blades images (interpolated to 256x256 for demonstration) (a), magnified details (b), and PROPELLER-EPI-reconstructed images (c) using the original 2D phase correction method, and their corresponding counterparts (d, e, f) obtained using our proposed approach.