Reverse Phase-encoding Versus Synb0-DISCO: Effect on Susceptibility Distortion Correction and Diffusion MRI Parameters

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Synopsis

Susceptibility-induced distortions displace and deform brain structures in diffusion MRI (dMRI), potentially causing regional analyses to sample signals from unintended tissues. How the choice of distortion correction method affects advanced diffusion models estimates with diffusion kurtosis imaging (DKI)[1] and neurite orientation dispersion and density imaging (NODDI)[2], relative to conventional diffusion tensor imaging (DTI)[3] metrics, warrants further evaluation. In this study, we compare classical TOPUP[4] using acquired reverse phase-encoding images with synthetic TOPUP using a synthetic undistorted b0 image generated by Synb0-DISCO[5]. We evaluate similarity between the corrected b0 images and agreement in downstream diffusion-derived parameters.

Impact

The Alzheimer's Disease Neuroimaging Initiative (ADNI) is a widely used, publicly accessible dataset for Alzheimer's disease research[6]. However, distortion correction availability varies across scanner vendors and study phases. This study supports retrospective dMRI data analysis and informs downstream metric comparability.

Introduction (740/750, Introduction- Conclusion, 3 Pages including figures and tables)

In ADNI, the availability of data to perform susceptibility distortion correction differs across scanner vendors and study phases. The advanced acquisition protocol for GE scanners incorporates correction during on-scanner reconstruction, whereas ADNI4 introduced an additional reverse phase-encoding acquisition for Philips and Siemens scanners. Many earlier ADNI datasets lack reverse phase-encoding acquisitions, limiting susceptibility distortion correction. With the availability of multi-shell diffusion MRI data, ADNI-based studies have increasingly used DKI and NODDI to investigate disease-related microstructural alterations[7]. However, reverse phase-encoding data are not consistently available, motivating us to evaluate how alternative distortion correction strategies affect these advanced diffusion parameters.

Methods

In this preliminary study, 30 ADNI participants with available multi-shell dMRI, paired posterior-to-anterior (PA) and anterior-to-posterior (AP) phase-encoding acquisitions, and T1-weighted images were selected, including 10 cognitively normal (CN) participants, 10 participants with mild cognitive impairment (MCI), and 10 participants with Alzheimer's disease (AlzD). Each group included five males and five females. The mean ages ± standard deviations were 69.60 ± 9.41 years for the CN group, 76.30 ± 5.66 years for the MCI group, and 76.30 ± 6.53 years for the AlzD group. All participants were scanned on the same 3 T Siemens MAGNETOM Prisma Fit scanner using a 64-channel head/neck coil. dMRI was acquired using a multiband EPI sequence (TR/TE = 3,400/71 ms, flip angle = 90°, slice thickness = 2 mm, voxel size = 2 × 2 × 2 mm^3, matrix size = 116 × 116 × 81). The PA acquisition included 13 b0 volumes and 6, 48, and 60 diffusion-weighted volumes at b = 500, 1,000, and 2,000 s/mm^2, respectively. The AP acquisition included one b0 volume and six volumes at b = 2,000 s/mm^2. T1-weighted images were acquired using an accelerated 3D sagittal MPRAGE sequence (TR/TE/TI = 2,300/2.98/900 ms, flip angle = 9°, slice thickness = 1 mm, voxel size = 1 × 1 × 1 mm^3, matrix size = 240 × 256 × 208). Each participant's PA diffusion data was processed using TOPUP with acquired PA–AP b0 images (FSL; https://fsl.fmrib.ox.ac.uk/fsl/)[4], or using TOPUP with the acquired PA b0 and a synthetic b0 generated by Synb0-DISCO (https://github.com/MASILab/Synb0-DISCO)[5]. The field estimates from the two approaches were supplied separately to FSL EDDY to correct the same PA diffusion data. Both pipelines used same processing steps, including brain extraction with FSL BET[8], motion and eddy-current correction with FSL EDDY[9], DTI and DKI fitting with DIPY (https://dipy.org/)[10], and NODDI fitting with AMICO (https://github.com/daducci/AMICO)[11]. DTI used b0 images and diffusion-weighted volumes with b ≤ 1,200 s/mm^2, whereas DKI and NODDI used all acquired shells. The derived parameters included fractional anisotropy (FA), mean diffusivity (MD), axial diffusivity (AD), and radial diffusivity (RD) from DTI; mean kurtosis (MK), axial kurtosis (AK), radial kurtosis (RK), and kurtosis fractional anisotropy (KFA) from DKI; and neurite density index (NDI), orientation dispersion index (ODI), and isotropic volume fraction (ISOVF) from NODDI. The processing pipeline is shown

in Figure 1. To compare the two methods, mean b0 images after EDDY correction were compared using structural similarity index (SSIM) and normalized cross-correlation (NCC), while diffusion parameter maps were compared using mean squared error (MSE), SSIM, and peak signal-to-noise ratio (PSNR). All comparisons were performed within a subject-specific mask.

Results

Figures 2 and 3 show mean b0 images and corresponding diffusion parameters for one CN participant with the highest b0 SSIM(0.93) and the AlzD participant with the lowest b0 SSIM (0.65), respectively. After EDDY correction, group median SSIM and NCC for mean b0 images ranged from 0.91 to 0.92 and from 0.92 to 0.93, respectively. Three participants with MCI and one with AD had both SSIM below 0.70 and NCC below 0.80 (Figure 4). Across all 30 participants, median SSIM was higher for DTI and DKI diffusivity maps (0.93–0.97) than for KFA (0.70) and NODDI parameters (0.77–0.90) (Figure 5).

Discussion

Agreement between pipelines was generally good for post-EDDY mean b0 images and DTI and DKI diffusivity maps, but was lower for b0 images in a few participants and for NODDI maps. The larger b0 discrepancies may be related to low SNR or specific image artifacts, while the lower agreement for NODDI may reflect greater sensitivity to noise, artifacts, or residual differences in image structure. Further work will identify the source of these differences and assess their implications for interpreting AD-related microstructural changes.

Conclusion

Synb0-DISCO showed good overall agreement with classical AP–PA TOPUP. Further validation is needed to determine whether these differences affect the interpretation of microstructural alterations in AD research.

References

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Figures

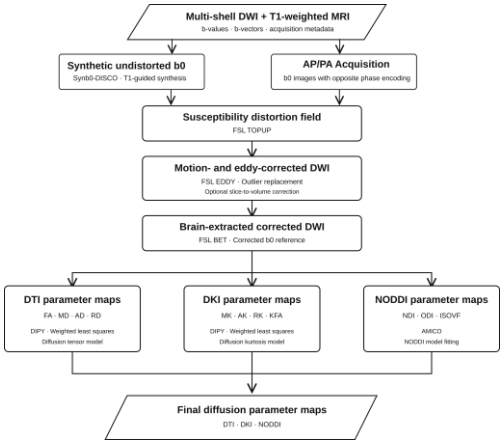


Figure 1. flowchart

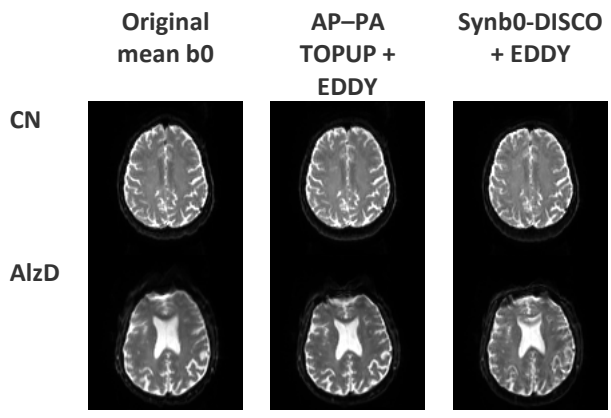
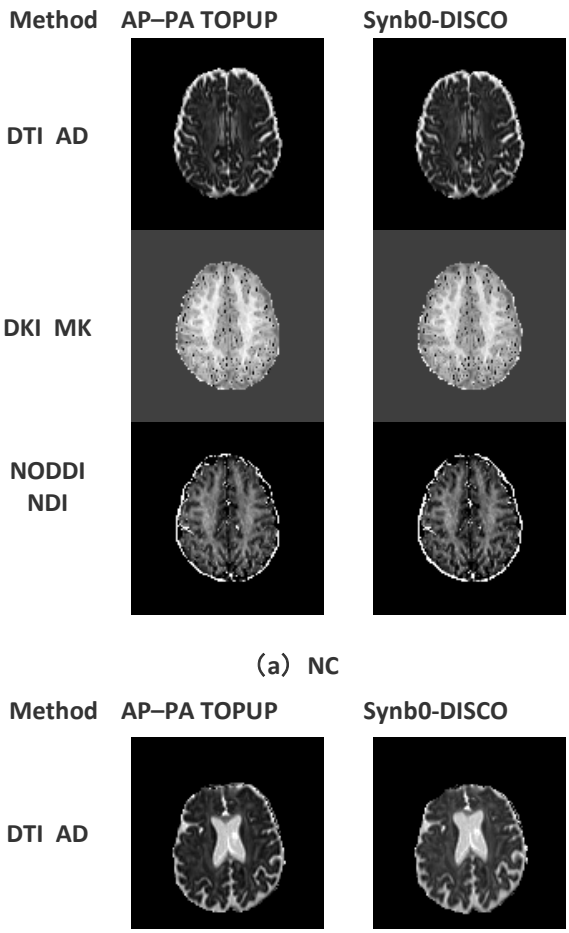


Figure 2. Mean b0 images before and after susceptibility distortion correction using TOPUP and Synb0-DISCO.



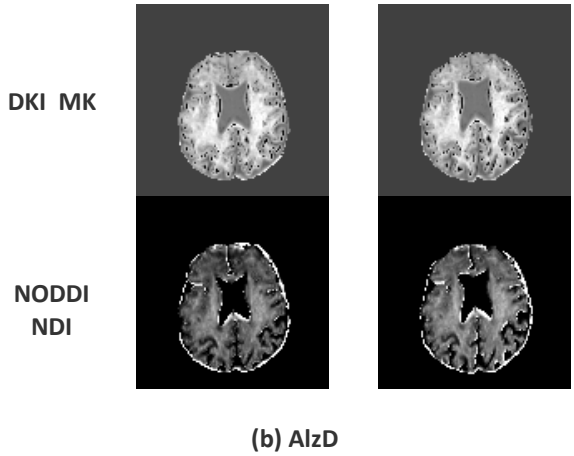


Figure 3. Representative diffusion MRI parameter maps from the two correction pipelines

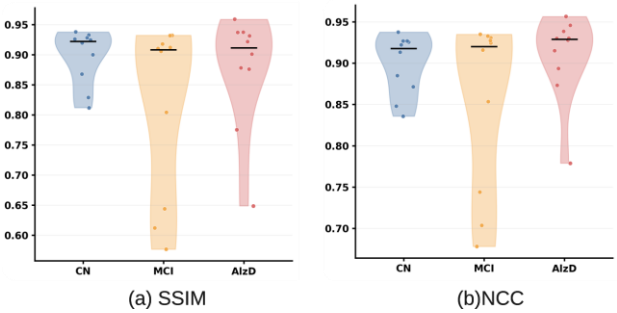


Figure 4. Agreement between post-EDDY mean b_0 images from the AP–PA TOPUP and Synb0-DISCO pipelines, by diagnostic group. (a) SSIM (left) and (b) NCC (right)

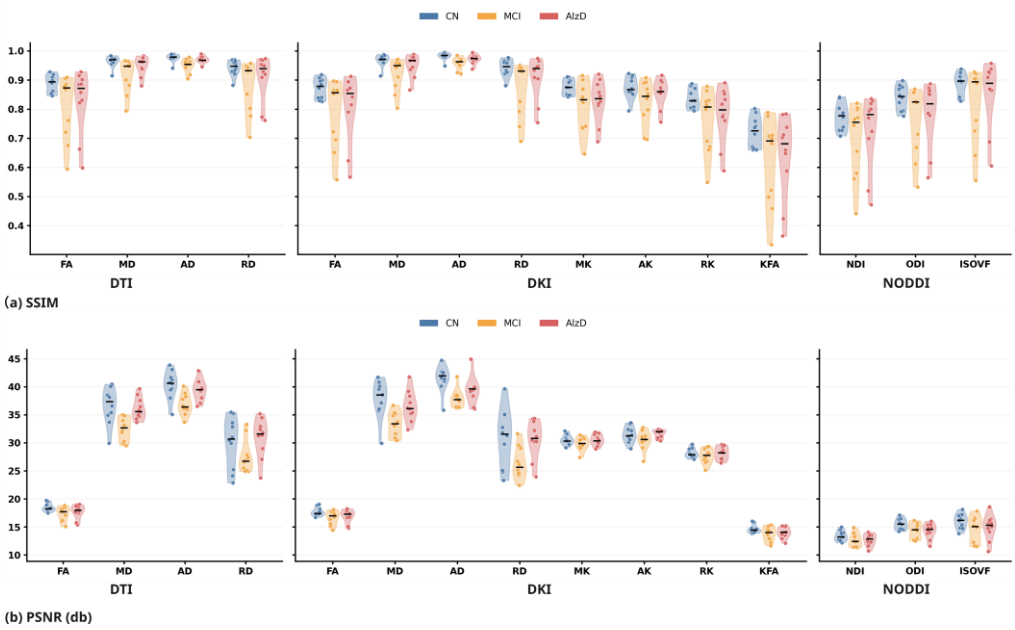


Figure 5. Agreement between diffusion parameter maps from the AP–PA TOPUP and Synb0-DISCO pipelines, by diagnostic group. (a) SSIM (top). (b) PSNR in dB (bottom).