Probabilistic Fiber Tracking at UHF: Effects of Distortion Correction and Reverse Phase Polarity Combination.

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Purpose/Introduction. For diffusion-weighted (DW) magnetic resonance imaging, single-shot spin-echo echo-planar-imaging (SE-EPI) is frequently used but prone to artifacts, which include eddy-current-induced (EC) and susceptibility-induced geometric distortions. Particularly, compressions cause loss of spatial information in the acquired image. This becomes a considerable challenge, especially at ultra-high field (UHF), where very strong local distortions appear. To resolve such problems, a pair of DW images with reversed phase-encoding polarity, leading to opposite distortions in the phase-encoding direction, is acquired and combined after distortion correction [1]. Recently, an extended point spread function (PSF) method [2-5] has shown that not only accurate distortion correction (DiCo) but also an adapted combination are very important to optimally preserve spatial information from the image pair. However, it is still not clear whether this combination does improve the structural connectivity information. To explore the effects, an analysis of probabilistic fiber tracking (ProbFT) [6] was performed for each DiCo procedure and the final result was compared with the reversed gradient polarity (RGP) approaches previously suggested [1].

Subjects and Methods. ***Data acquisition.*** Two healthy volunteers were scanned on a 7T whole-body MR scanner (Siemens AG, Healthcare Sector, Erlangen, Germany). PSF data were acquired with an acceleration factor of 3 in the PSF dimension (corresponding to 60 EPI repetitions) to calculate EPI distortions. Forward (fwd) and reverse (rev) phase encoded (PE) DW EPI acquisitions, which resulted in pairs of DW images with opposite distortions in the phase-encoding direction, were acquired with a Stejskal-Tanner diffusion scheme. The experimental protocols for EPI and PSF scans were TR/TE=5910/56 ms, echo-spacing=0.71 ms, pixel bandwidth 1532 Hz, voxel size 1.2 mm^3, matrix 180^2, 80 transverse slices without gap to cover the entire brain, GRAPPA factor 3 with 48 reference lines, partial Fourier 6/8. The dataset included a non-DW image with *b*-value=0 s/mm^2 and 30 DW images with non-collinear gradient directions and *b*-value=1000 s/mm^2.

Image processing. Data were corrected by the extended PSF-based DiCo with weighted combination [2-4]. RGP DiCo methods with least-squares restoration (LSR) and Jacobian modulation (JacM) algorithm [1] were also applied for comparison. To evaluate the improvement, data sets without correction, EC correction, PSF-based DiCo for fwd or rev EPIs were also generated. Based on those data sets, fractional anisotropy (FA) maps were calculated and ProbFT was performed under the assumption of two (f2) fibers per voxel [7]. To verify changes of local probabilistic connectivity density due to the corrections, we selected the midsagittal genu of the corpus callosum as seed mask for ProbFT (Fig.1I, orange color) since this area is generally connected to prefrontal areas of the brain, where severe local distortions appear. Due to different geometries in images with and without DiCo, the masks were manually adjusted. For visualization, final ProbFT maps were calculated by summation across three slices from each ProbFT data set and then identically normalized. As a quantitative measure, the total number of voxels in ProbFT maps was counted keeping 50% threshold of the maximum of the connectivity density.

Results/Discussion. Figure 1 demonstrates that EC- and susceptibility-induced geometric distortions can degenerate probabilistic connectivity or even disrupt it. Strongly stretched geometric distortions from corpus callosum to prefrontal regions appear in fwd EPIs and vice versa in rev EPIs (see Fig. 1II-c-f dashed line in FA maps). Such geometrical distortions lead to missing connectivity density, which can be unveiled by EC correction (Fig. 1II-c and 1II-d). The local connectivity density can be further improved by PSF-based DiCo for fwd and rev EPIs (Fig. 1II-a and 1II-b). However, the pattern of connectivity density is different between fwd and rev ProbFT maps due to different loss of spatial information caused by opposite distortions (see arrows in Fig. 1II). With the weighted combination, the probabilistic connectivity density from the image pair was preserved very well in the final ProbFT map (Fig. 1III-a). In contrast, only the major connectivity density, which exists in both fwd and rev ProbFT maps, was preserved in the final ProbFT maps obtained by the RGP methods (see arrows in Fig. 1III-b and 1III-c). The results of the quantitative ProbFT analysis (Fig. 2) confirm these visual impressions .

Conclusion. This study demonstrates that the connectivity density in the ProbFT maps can be improved by corrections as well as by suitable combination of the image pair. In other words, optimally preserving of spatial information from the image pair can strengthen the structural connectivity information of the brain. Therefore, the method can be a good choice to provide distortion-free DW images and to utilize the connectivity information for diffusion studies.

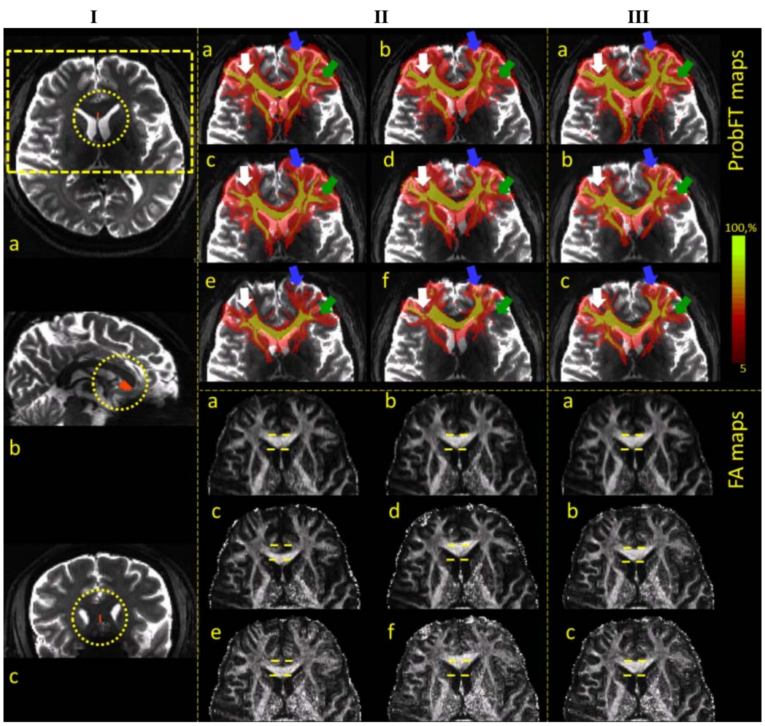

Fig.1. (**I**) Distortion-free anatomical reference image in orthogonal view (**a**-transverse, **b**-sagittal, **c**-coronal) overlaid with the seed mask (orange color) highlighted by circle. (**II**) fwd (1st column) and rev (2nd column) ProbFT and FA maps with no correction (**e** and **f**), EC correction (**c** and **d**), and both EC and PSF DiCo (**a** and **b**). (**III**) The final ProbFT and FA maps with extended PSF based DiCo weighted combination (**a**) and two final maps obtained by RGP methods with JacM (**b**) and LSR algorithms (**c**). Rectangular region of interest (ROI) for these maps is shown in (**I**). All ProbFT maps are overlaid on a representative transverse slice with *b*-value=0 s/mm^2, which is identical to the slice position of the transverse reference slice (**I-a**). Color-bar represents a scale of ProbFT maps normalized identically to 100%. Most significant differences in ProbFT maps are pointed by arrows and yellow dash-lines in FA maps indicate different amount of distortion near the corpus callosum.

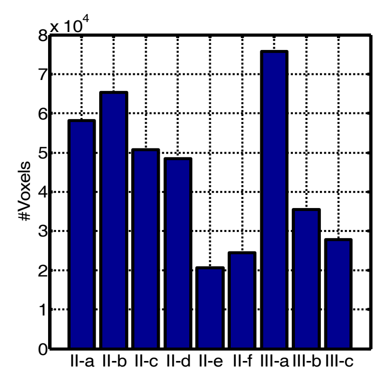

Fig.2. The total number of voxels in ProbFT maps of Fig. 1II-a-f and III-a-c.

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