CONSTRUCTION OF GROUND-TRUTH DATA FOR HEAD MOTION CORRECTION IN DIFFUSION MRI

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Purpose: Head motion correction is one of the most important preprocessing steps for diffusion-weighted (DW) MR data, as the scalar indices used in many clinical studies, such as FA, are highly sensitive to motion artifacts. One issue regarding retrospective motion correction is the difficulty in performing a proper evaluation of the employed algorithms, as no *ground-truth* is provided and a manual detection of anatomical landmarks for a quantitative evaluation of the target registration error (TRE) is not practicable due to the huge amount of images included in a single DW dataset. Hence many studies only provide a qualitative visual evaluation[1,2] or descriptive measures like the intensity variance[2]. An evaluation of the TRE is possible when adding motion to already aligned DW datasets. However, since the DW signal strongly depends on the orientation, this method is limited to adding translational motion. Recently, the Fiberfox[3] tool for simulating realistic DW software phantoms based on a model of the underlying fiber structures was presented as part of the open-source MITK toolkit. We present an extension of Fiberfox that allows simulation of motion during the image acquisition, particularly rotational movement. We show that the rotational component must not be neglected in the evaluation of correction algorithms.

Methods: Fiberfox generates a DW MR signal by simulating the k-space acquisition employing state of the art multi-compartment modeling techniques. Input for the simulation is a complete tractogram together with the desired DW acquisition parameters. To simulate motion during the acquisition, the tractogram used for the signal simulation is transformed with respect to the defined rotational and translational parameters. Fiberfox allows for adding a random translation and rotation or a steady motion over the complete acquisition time. The individual transformation steps are applied to the tractogram after the simulation of each gradient volume.

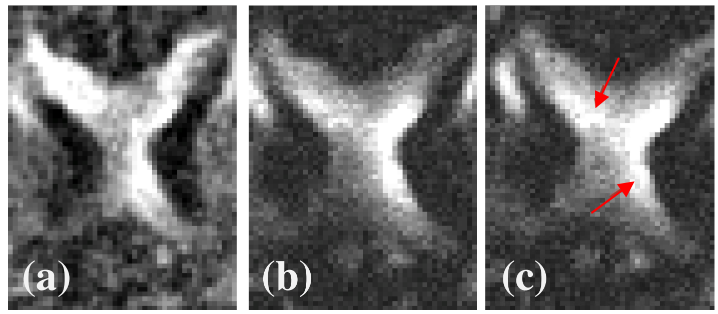

Fig. 1 Original (a), simulated (b) and transformed (c) image. Note the rotation-induced intensity change (red arrows)

Starting with a tractogram computed on an aligned dataset included in the Human Connectome Project[5] database (1.25 mm isotropic voxel, 90 gradients at b=1000, 2000 and 3000 s/mm^2 and 18 at b=0 s/mm^2), two simulations were performed. One dataset was generated while randomly translating the tractogram ([-5, 5] voxels). For comparison, the aligned original dataset was distorted in same manner. In the second experiment a continuous linear motion with maximum translation of 10 mm and maximum rotation of 15° was simulated. The motion was corrected by means of parametric registration using a multi-scale approach with regular step gradient descent optimizer as provided by ITK[4]. Following the common used correction scheme, all gradient images were registered to the first unweighted image by maximizing the mutual information image metric. To quantify the alignment error, the *target registration error* (TRE) was computed over landmarks uniformly distributed in the image.

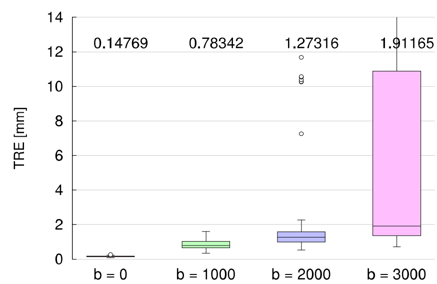

Fig. 2 TRE at different b-values for the motion distorted original aligned data.

Results: The TRE of the correction of the original dataset distorted by random translations is shown in Fig. 2. The error increases with increasing b-values and reaches values in the order of the voxel-size for b-values over 2000 s/mm^2. In Fig. 3 (a) the TRE of the simulated data distorted by random translation is shown. Again the error increases with increasing b-values, however on a smaller scale The TRE of the correction of the simulated data distorted by both translation and rotation is shown in Fig. 3(b). Here the error is significantly ($p < 0.01$) higher than for translational motion only.

Discussion and Conclusion: We have presented a method for the reference-based evaluation of head-motion correction in diffusion MR. We showed that rotations must not be neglected in motion correction and evaluation. The overall low TRE for the simulated data distorted only by translation compared to the original ones results possibly from the high SNR in the simulated data for higher b-values – first only thermic noise was simulated among the artifacts provided by Fiberfox and second the simulation was not optimized to perfectly mimic the contrast of the original acquisition. Compared to the small error for translation distortions, the much higher TRE on the data simulated with rotational motion underlines the high importance of rotation simulation. One limitation is the assumption that the motion occurs only between the gradient images. A scheduled enhancement is to simulate the continuous motion in a more realistic, non-linear, fashion.

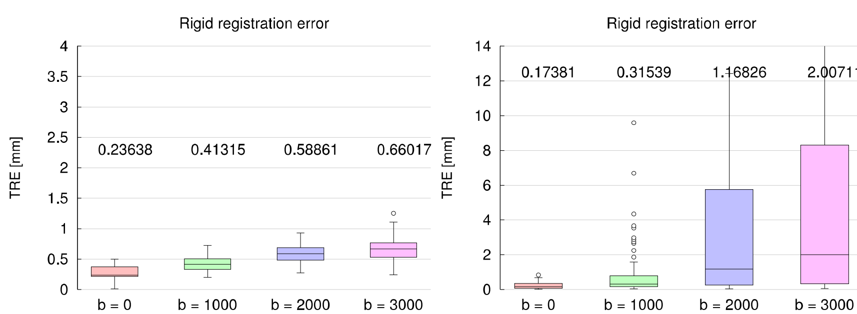

Fig. 3 Target registration error at different b-values for the correction of simulated data for random translation (a) and continuous translation and rotation (b).

References: [1] Ben-Amitay *et al.*, MRM 2012,67(6):1694-1702 [2] Huizinga *et al*. CDMRI MICCAI 2013, in press [3] Neher *et al*., MRM 2013, accepted [4] Insight Toolkit, www.itk.org [5] David C. van Essen *et al.*, Neuroimage 80(2013):62-79