A SIMPLE MODEL FOR EDDY CURRENTS CORRECTION IN HIGH B-VALUES ACQUISITIONS

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Introduction: In the last decade, several innovative approaches were proposed [1-3] to investigate diffusion in brain beyond conventional DTI. Such models share the need to explore low as well as high b-values (up to 10000s/mm^2) to achieve a deeper characterization of local microstructure. Diffusion weighted (DW) images are known to be affected by eddy currents (EC's)-induced distortions. The standard approach to correct for EC's is an affine registration of DW images with respect to the T_2-weighted images, but several methods have been proposed to reach a better alignment [4-6]. So far, none of them specifically addressed the issue of high b-values: with increasing diffusion weighting, EC distortions become more severe and affine registration is challenging, due to the progressive disappearing of anatomical landmarks. We propose here a simple model for EC's corrections. The EC's should scale according to the gradient amplitude and their effect can be described by a scale, a shear and a shift in the phase-encoding direction [4]. However, in standard affine registration there is nothing to constrain the corrections due to EC's to be self-consistent. Our proposal is to first test that the linear model works for EC's by looking at a phantom, where the EC's induced shift is not combined with subject motion. By means of the proposed pipeline, we calculate the distortion corrections on a low b-value subset of measurements, extrapolating regressed estimates under linearity assumptions. A transformation matrix is then generated to correct high b-values data. Having shown that it works, we then apply the same transformation matrix on human brain data and evaluate the obtained results comparing the goodness of fit according to the CHARMED protocol [3].

Methods: A CHARMED protocol [1] was applied on a tetradecane phantom at 3T. We chose tetradecane, out of other suggested test liquids for quality control in diffusion sequences [7], due to its long T_2 and low diffusion coefficient, of the same order of that measured in brain during high b-values acquisitions. DW data (TR/TE=6000/122ms,Δ/δ=50/43ms) were obtained at b-values of 937, 1875, 2812, 3750, 4687.5, 5625, 6562.5 and 7500s/mm^2 across 192 directions. A b=0 s/mm^2 image was interleaved every 20 scans. The same protocol with TR=12000ms was applied on one healthy young subject. DW data on phantom were registered to the b=0 s/mm^2 image allowing 3 DoF in the FLIRT (FSL, FMRIB, Oxford) schedule, thus obtaining scale, shift and shear parameters in the phase-encoding direction. Each parameter was expressed as a linear combination of the gradient intensity on read, phase and slice directions (since each of them can generate EC along the phase direction) and the coefficients expressing this proportionality were evaluated by linear regression. Due to the poor registration of high b-values images (caused by low SNR), only images whose mean intensity was higher than 10% of the b=0 s/mm^2 image mean intensity are considered in our linear model (colour data points in Fig1b). For each gradient direction, a transformation matrix was then generated and applied to high b-values data. The same transformation matrix was also applied to the in-vivo data, followed by a rigid body registration with respect to the b=0 s/mm^2 image (to correct for subject's motion). Uncorrected and corrected brain data, as well as a dataset corrected with conventional affine registration (FSL-FLIRT), were analysed with CHARMED model and $\chi 2$ maps were obtained.

Results: The pre-processing pipeline is schematized in Fig.1a-c. Fig1b reports the correlation between the distortions and the gradient amplitude. In Fig.1d, $\chi 2$ maps are reported for uncorrected data (left), data corrected by means of conventional affine registration (middle) and with the proposed pipeline (right). Both correction procedures improve the fit quality with respect to the uncorrected data, but that presented in this work generates lower $\chi 2$ maps (as shown in the upper panel of fig.1d), despite the reduce number of DoF.

Conclusion: We propose here a simple but versatile pre-processing pipeline for EC's correction, especially suited for high b-values applications. The procedure is demonstrated to improve the fit quality when a CHARMED data analysis is performed. Furthermore, the regressed estimates can be also evaluated directly on the brain data, once a model for motion-induced distortions is introduced [8].

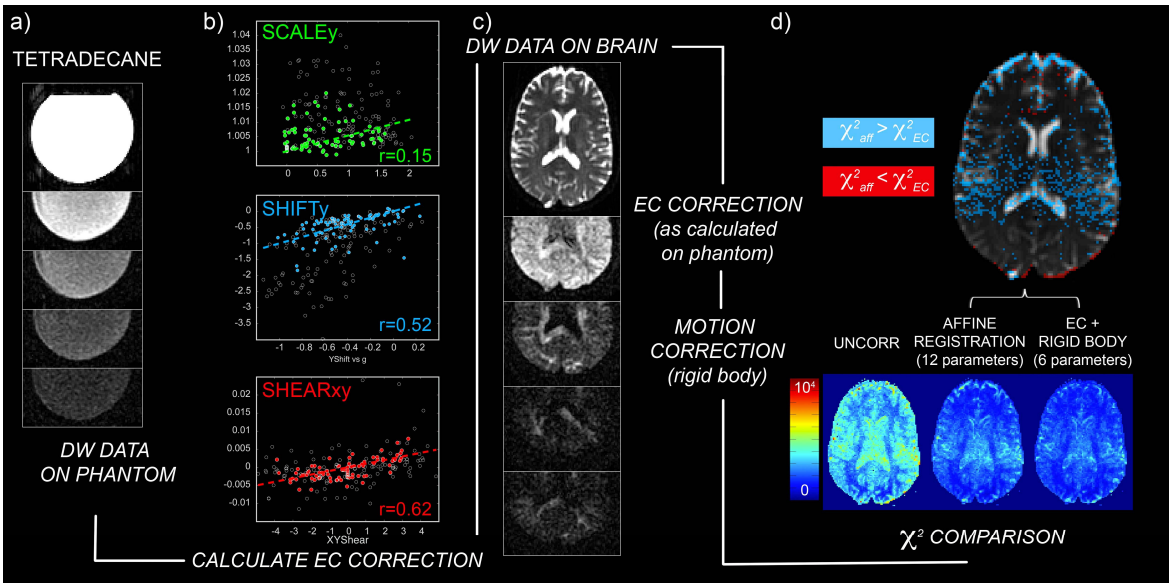

Fig1 Pre-processing pipeline for EC's correction of DW data on phantom and in vivo. a) DW data acquired on a tetradecane phantom. b) Scale, shift and scale along phase encoding directions are obtained by registration to the b=0 s/mm^2 image allowing 3 DoF. The coefficients that link each distortion to the gradient intensity under linear assumptions are obtained with linear regression and used to generate a transformation matrix from EC's-distorted to undistorted space. c) DW data are acquired in-vivo and corrected for EC's applying the transformation matrix generated on the phantom. Afterwards, motion artefacts are corrected with a rigid body registration with respect to the b=0 s/mm^2 image. d) Uncorrected, conventionally corrected (affine registration) and corrected datasets are used to generate $\chi 2$ maps using CHARMED model. In the upper panel, the voxels in which $\chi 2$ is improved by 25% or more with affine registration are reported in red while the voxels in which $\chi 2$ is improved by 25% or more with our correction scheme are reported in light blue.

References: [1] Assaf Y et al., Magn Reson Med 2002;47:115 [2] Tuch DS et al., Neuron 2003;40:885 [3] Assaf Y and Basser P NeuroImage 2005;27:48 [4] Haselgrove JC and Moore JR, Magn Res Med 1996;36:240 [5] Anderson JLR and Skare S, NeuroImage 2002;16:177 [6] Rohde GK et al. Magn Res Med 2004;51:103 [7] Toft et al. Magn Res Med 2000;43:368 [8] Ben Amitay S et al, submitted abstract