Diffusivity in crossing and diverging fibers: a multi-site phantom experiment

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Introduction. Multi-site studies into neurological and psychiatric diseases are being increasingly employed to collect data from larger populations, adding statistical power and improving the generalizability of results. Studying complex diffusion models *in vivo* in the human brain is challenging because of the unknown underlying anatomy. Measuring artificial diffusion phantoms allows for comparing parameter estimates to known fiber configurations and microstructure [1,2]. Here we aim to study diffusion parameters within a diffusion phantom scanned on two sites.

Materials & Methods. Measurements were performed on a multisection diffusion phantom made of polyethylene fibers tightly wound on an acrylic support. The phantom contains a region with perpendicularly crossing fibers, a region with parallel fibers and homogeneous density, and a region with parallel fibers with a gradient of fiber density along the axis of symmetry ('diverging fibers') [1].

Data were acquired on two 3 Tesla scanners: (1) a wide-bore Siemens Verio system and (2) a Siemens Trio scanner, equipped with 32- and 12-channel head coils respectively. The phantom was positioned such that both crossing fiber bundles were at an angle of 45 degrees with the main magnetic field. Coronal diffusion weighted images (DWIs) were acquired, scanning parameters were TE/TR=110/8700 ms; data matrix 96x96; voxel size 2.5x2.5x2.5 mm^3; diffusion sensitivities of b=0, 700, 1000 and 2500 s/mm^2; 10, 25, 40, 75 field gradient directions per corresponding *b*-value (150 in total); 20 continuous slices (no slice gap); GRAPPA factor of 2 in the AP-direction; scanning time 22.1 minutes.

Three methods for data analysis were employed: (1) diffusion tensor imaging (DTI), or single tensor (ST) model; (2) a dual tensor (DT) model with an isotropic volume fraction and constraints on eigenvalues of the anisotropic tensors to be equal and an isotropic diffusivity of $3.0.10^{-3}$ mm^2/s [3], (3) diffusion kurtosis imaging (DKI) [4]. All models were estimated by Maximum Likelihood Estimation. The DT-model included an estimation of the noise level, σ, from which the corresponding $SNR=S_0/\sigma$ was computed. Fibers were tracked using Constrained Spherical Deconvolution (CSD) in ExploreDTI [5]. Diffusion parameter profiles were computed in fibers tracked in the top and bottom part of the phantom. Ten clusters were positioned along the fibers and data perpendicular to the axis of symmetry was pooled.

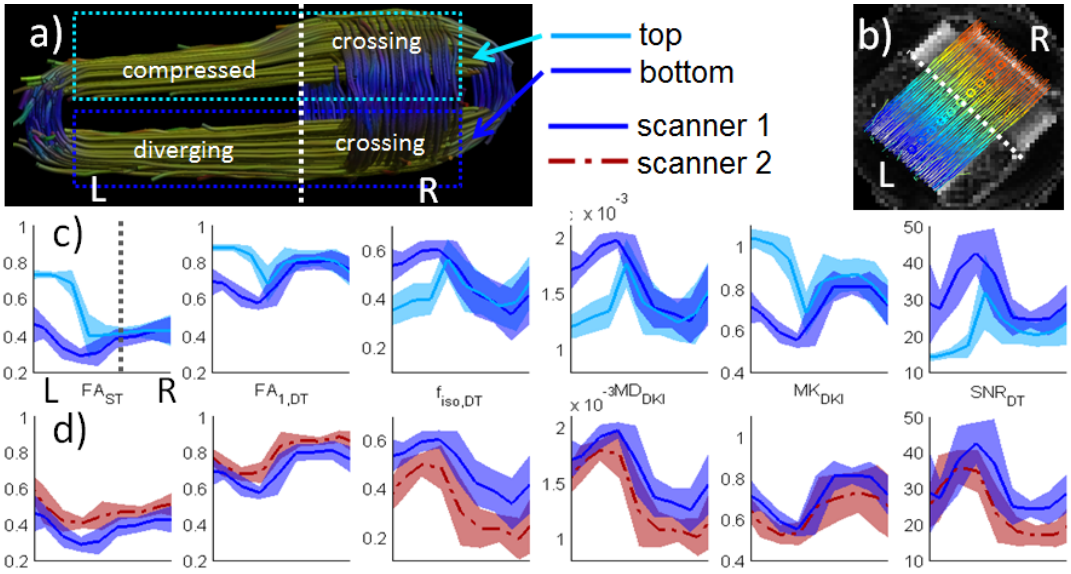

Figure. a) Side view of tracked fibers in the phantom. Top fibers pass through compressed parallel fibers and a crossing, bottom fibers diverge in the gradient part and then pass through a crossing. Through plane fibers are not analysed. b) Top view of fibers superimposed on single tensor FA, colored according to closest cluster center point. c) Estimated mean and standard deviation of diffusion parameter profiles of top and bottom fibers measured on scanner 1 and d) bottom fibers measured with different scanners. Parameters from left to right: single tensor Fractional Anisotropy (FA_{ST}), dual tensor $FA_{1,DT}$ and isotropic volume fraction $f_{iso,DT}$, Mean Diffusivity (MD_{DKI}) and Mean Kurtosis (MK_{DKI}) from Diffusion Kurtosis Imaging (DKI), SNR_{DT}.

Results. All parameters differed more than one standard deviation between the homogeneously compressed region and the region with a gradient in fiber density. In the 'gradient' region, all parameters were dependent on the fiber density. In the compressed region only ST parameters are constant, which suggests that the other parameters are more sensitive to minor microstructural changes. FA_{ST} showed a more than two-fold drop between the compressed and crossing areas. A nearly two-fold difference between FA_{ST} and $FA_{1,DT}$ in the crossing area is seen. Comparing data between scanners shows a (constant) offset in all parameters. The magnitude of the offset was smaller than one standard deviation from the mean profiles. SNR variation is driven by a dependence of S_0 on fiber density (data not shown), as well as the coil sensitivity profile.

Conclusion. Multi-site comparison of complex diffusion models is possible using a multisection phantom. This approach gives insights into which parameters are most appropriate for human studies conducted using multiple scanners at different sites.

References. [1] E. Farrher et al., *Magn. Reson. Imaging* 30, 518-526 (2012); [2] F. Grinberg et al., *Micropor Mesopor Mat*, 178,44-47 (2013); [3] M.W.A. Caan et al., IEEE TMI 29 (8), 1504-15 (2010); [4] J.H. Jensen et al., *Magn. Reson. Med.* 53, 1432-1440 (2005); [5] A. Leemans et al., *Proc. ISMRM* 17, 3537 (2009)