Mapping Crossing Fibres of the Human Brain with Spherical Deconvolution: Towards an Atlas for Clinico-Anatomical Correlation Studies

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Introduction: Clinical manifestations of subcortical neurological conditions are correlated with the severity of damage to long and short white matter connections. Hence, the development of MRI-derived quantitative measurements of fibre damage could have important applications for prognosis and treatment planning. In recent years Spherical Deconvolution (SD) has been applied to diffusion imaging to improve the visualization of multi-fibre orientation in brain regions with fibre crossing [1][2]. In this work we have used the information from the Fibre Orientation Distribution (FOD) to quantify the number of fibre orientations in each voxel. Maps of the Number of Fibres Orientations (NuFO) were created from a central region of the cerebral hemispheres and compared with fractional anisotropy maps.

Methods: Diffusion MR data were acquired from 5 normal brains on a 3T GE Signa HDx TwinSpeed system (General Electric, Milwaukee, WI, USA) with the following parameters: voxel size 2.4x2.4x2.4 mm, matrix 128x128, slices 60, NEX 1, TE 90 ms, b-value 3000 s/mm^2, 60 diffusion-weighted directions and 6 non-diffusion-weighted volumes, using a spin-echo EPI sequence. Cardiac Gating was applied with an effective TR of 20 R-R intervals. Deconvolution was performed using a damped version of the Richardson-Lucy Spherical Deconvolution algorithm [2] and, for each voxel, local maxima of the FOD estimated. NuFO maps were obtained as the number of distinct local maxima detected in each voxel. To exclude spurious local maxima two thresholds were applied (Figure 1). A first "absolute" threshold was used to exclude small local maxima due to noise and isotropic tissue. Different values of the absolute threshold were compared using multiples of the amplitude of spherical FOD obtained from a gray matter isotropic voxel (D = 0.7 mm^2/s) as a reference amplitude (A_{iso}). A second "relative" threshold was applied to remove remaining local maxima with value greater than the absolute threshold but whose value was relatively small compared to the maximum amplitude of the corresponding FOD, thus suggesting a spurious origin. Maps with different combinations of absolute and relative thresholds were generated and compared. Color coding was applied to create maps indicative of the number of fibre orientations from zero (black), one (red), two (orange) to more than two (yellow).

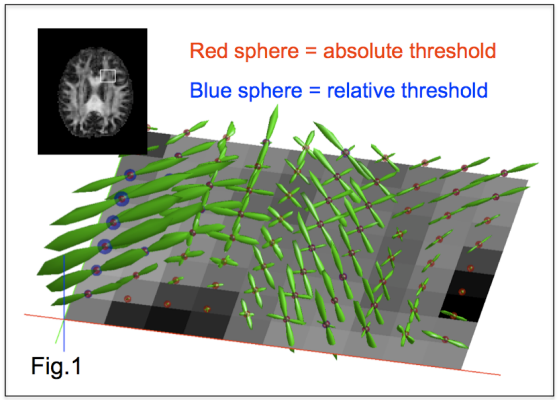

Fig.1

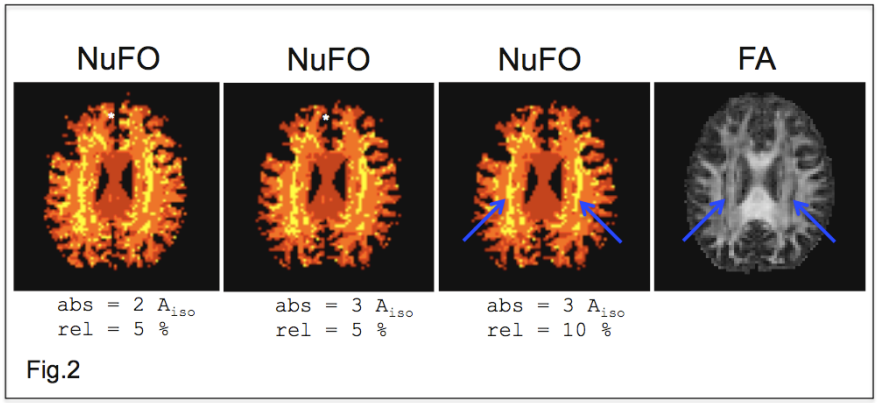

Fig.2

Results: In Figure 2, NuFO maps are shown for different threshold levels on the same selected slice. It is possible to visually distinguish different brain regions that are faithful to the known anatomy derived from histological studies according to the number of fibres orientations [3]. For example the body of the corpus callosum, which contains fibres with a single orientation, is separated from the corona radiata, which contains two populations of crossing fibres (i.e. corpus callosum and cortico-spinal tract). Lateral to the corona radiata there is a yellow region, indicated by blue arrows, known to encompass at least three populations of crossing fibres (i.e. corpus callosum, cortico-spinal tract, arcuate). This region is also visible as an area of low anisotropy in the FA map. The number of periventricular fibre orientations in the corona radiata reduces from more than two (anatomically inconsistent) to one or two orientations when increasing the absolute threshold, from 2 A_{iso} to 3 A_{iso},. Similarly, in regions close to cortical gray matter (white asterisk) the number of fibre orientations decreases from one or more than one to zero (i.e. an increase in the number of black voxels). The use of an absolute threshold failed to remove voxels with multiple orientations in regions where single fibre orientations are expected (i.e. corpus callosum). In these regions with high anisotropy the use of higher value relative threshold (10%) eliminates spurious crossing. Results were consistent among all subjects acquired.

Discussion and Conclusions: Using information derived from Spherical Deconvolution we were able to produce maps that provide further information on the complexity of white matter anatomy as reflected by the number of crossing fibres. One of the limitation related to most approaches which aim to estimate multi-fibre distribution is their limited ability to discriminate true from artifactual fibre orientations, or their inability to resolve crossing for more than two orientations [4][5]. Spherical Deconvolution offers the possibility of reducing spurious spikes by applying an absolute threshold to the FOD amplitude in order to reject false orientations. Spurious spikes are more likely to occur in regions with low anisotropy, where the low signal intensity generates low FOD amplitudes due to their linear relationship in the spherical deconvolution model. In this work, by combining an absolute threshold of 3 A_{iso}, that is effective in removing spikes throughout most regions of the brain, and a relative threshold value of 10%, which was effective in high anisotropic tissues, we were able to correct most of the anatomically inconsistent NuFO voxels. We propose that these maps may be used to create an atlas for clinico-anatomical correlation studies in a number of conditions including, multiple sclerosis, brain tumours, vascular dementia and other stroke-related disorders. The direct application of this method to patients with neurodegenerative diseases could allow us to better quantify the selective involvement of specific pathways underlying cognition and behaviour.

References: [1] Tournier JD *et al.* NeuroImage 23:1176-1185 (2004); [2] Dell'Acqua F *et al.* Proc. 16th ISMRM: 1860 (2008); [3], Bürgel U *et al.* NeuroImage 29 (4): 1092-105 (2006); [4] Alexander DC *et al*, MRM 2002; 48:331-340 [5] Nedjati-Gilani S *et al.* Proc. 14th ISMRM: 3169 (2006);