Development of a WM atlas based on anatomical connectivity mapping

M. Cercignani[1], K. Embleton[2], G. J. Parker[3], and M. Bozzali[1]

[1]Neuorimaging Laboratory, Santa Lucia Foundation, Rome, Italy, [2]Cognition and Cognitive Neuroscience Group, School of Psychological Sciences, University of Manchester, United Kingdom, [3]Imaging Science & Biomedical Engineering and the Biomedical Imaging Institute, University of Manchester, United Kingdom

Introduction

Diffusion Tensor (DT) MRI has become the prefered imaging tool for visualising white matter (WM) anatomy, thanks to its ability to characterize the orientation of WM fibre bundles. A number of WM atlases (1,2) based on DT-MRI have been developed. Typically, the orientational information, derived from the direction of the principal eigenvector and summarised by a red-green-blue colour coding is displayed, modulated by fractional anisotropy (FA) in order to highlight WM structures only. These images provide an excellent description of highly directional WM structures. Recently, a measure of anatomical connectivity derived from DT MRI tractography has been proposed (3). Anatomical connectivity mapping (ACM) is obtained by initiating streamlines from all parenchymal voxels, and then counting the number of streamlines passing through each voxel of the brain. ACM provides a type of information that is complementary to FA, as it highlights WM structures which are strongly connected (but not necessarily highly directional) to the rest of the brain. We propose the use of ACM to develop an atlas of WM, providing information which is complementary to that available form FA.

Methods

Ten right-handed subjects (F/M=5/5, median age [range]= 28 [22-34] yrs) have been recruited so far for this study. DT MRI was obtained at 3T (Siemens Magnetom Allegra) using a twice-refocused spin echo EPI (TE/TR=90/8500ms, b_{max}=1000smm^{-2}, 81 directions, 9 b_0s, 60 slices, voxel size 2.3mm^3). All subjects had also a T1-weighetd 3D scan (MPrage, TE/TR=2.74/2500 ms; TI=900; flip angle=8°; voxelsize=1mm^3), which was segmented into WM, grey matter and CSF using SPM8 (4, www.fil.ion.ucl.ac.uk/spm/). DT MRI data were first corrected for eddy current induced distortion using an affine transformation matching all volumes to the first b_0 image (the tool used is part of FSL, www.fmrib.ox.ac.uk/fsl/). All the remaining processing of DT MRI data was done using Camino (www.camino.org.uk), if not otherwise specified. The diffusion tensor was estimated in every voxel, and maps of FA were obtained for every subject. The non-linear transformation matching every subject's FA to the FSL FA template in MNI coordinates (1mm^3 resolution) was estimated using FNIRT (part of FSL), and applied to each component of the diffusion tensor. In order to preserve the directional information, the preservation of principal direction algorithm (5) was used. Each component of the tensor was then averaged across subjects to yield a mean diffusion tensor. FA and the principal eiegenvector were computed. Probabilistic tractography based on the probabilistic index of connectivity (PICo, 6) with 10 Monte Carlo iterations was initiated from all voxels in the parenchymal mask. The ACM of the mean tensor was obtained by counting the total number of streamlines passing through each voxel and normalised it by the total number of streamlines initiated.

Results

Fig 1 shows colour coded ACMs obtained from the mean tensor. Several structures typically visible on colour-coded FA maps (shown on Fig 2 for comparison) are visible also on ACM. Many other structures, however, can be seen more clearly and with greater resolution on the ACM images, with well-connected parts of white and grey matter being particularly visible. Note also the left/right asymmetry, particulalry visible around Broca's area, which fits with the functional specialization of the two hemispheres.

Fig 1. Colour-coded ACM map obtained from the mean Tensor.

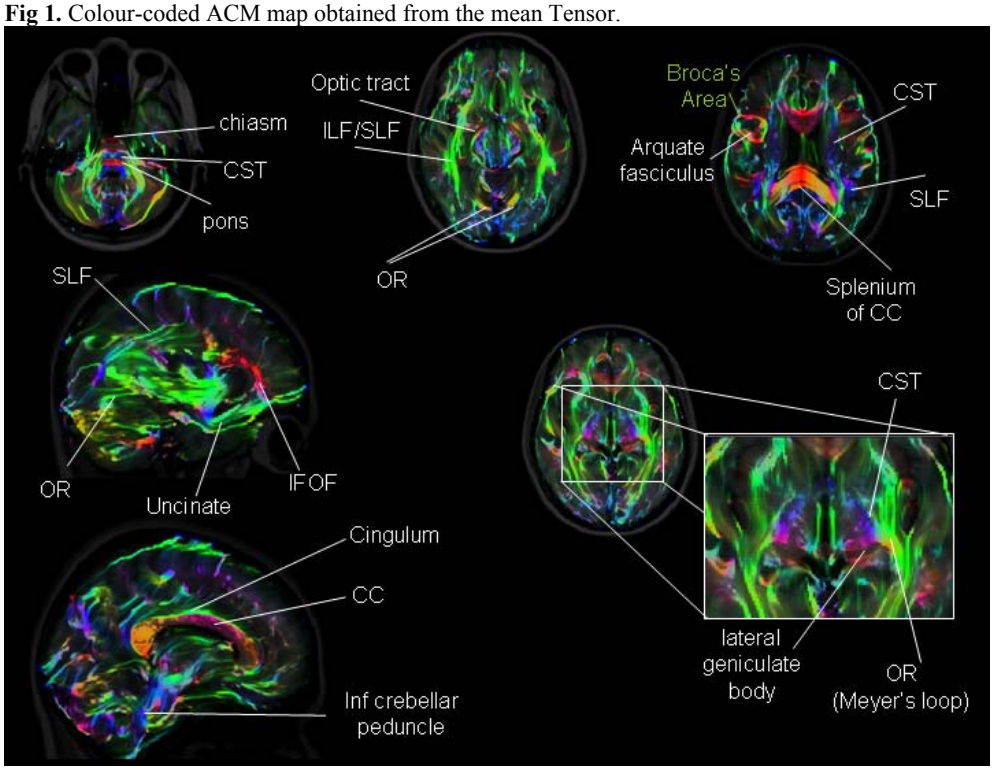
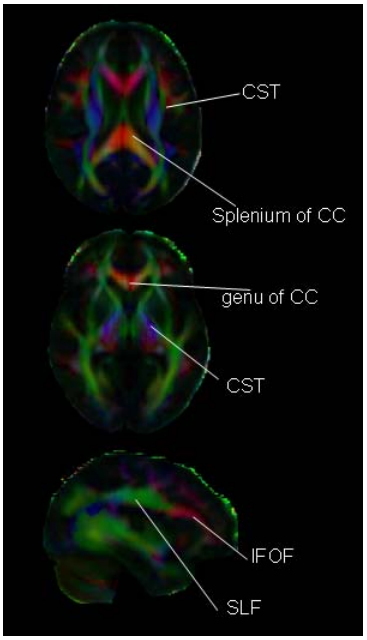


Fig 2. Colour-coded FA map obtained from the mean Tensor.



CC = corpus callosum
CST = cortico-spinal tract
ILF = inferior longitudinal fasciculus
IFOF = inferior fronto-occipital fasciculus
SLF=superior longitudinal fasciculus

Discussion & Future work

ACM provides information complementary to that offered by FA by emphasising white matter and grey matter that is strongly connected to other regions. An atlas based on both indices can be helpful for educational and clinical purposes, with particular utility in providing a reference standard for the identification of abnormalities and pathology. Embleton et al. (3) originally suggested to use a high angular resolution diffusion model, such as Q-ball (7), rather than the tensor, to derive ACMs. Our work demonstrates the general applicability to simpler models of diffusion. We are currently implementing algorithms for rotating the principal directions derived from q-ball, in order to obtain an improved version of this WM atlas. The recruitment of additional healthy subjects is ongoing.

References

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