On the importance of appropriate fibre population selection in diffusion tractography

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Introduction

A great deal of recent research in diffusion MRI has focussed on improved modelling and reconstruction of multiple white matter fibre orientations within single image voxels. These methods are typically used to create an orientation distribution function (ODF) at each voxel, which represents the orientations of each fibre population crossing the voxel. However, very little attention has been given to the important problem of how a tractography algorithm should best navigate through the resulting field of ODFs. By far the commonest approach is to apply a continuity criterion, whereby a candidate propagation direction is selected whose orientation most closely matches the direction of entry to the voxel—but this assumption of smoothness dramatically oversimplifies the variety and complexity of tract shapes in the brain. "Global" approaches to tractography (e.g. [1,2]) offer a more sophisticated approach, but generally require substantially greater computation time. Here we propose a simple alternative strategy, based on prior knowledge, in which fibre population selection is based on the local orientation of a predefined reference tract.

Methods

Eight healthy young subjects (4 male, mean age 31.9 ± 5.3 yr) underwent a diffusion MRI protocol on a GE Signa LX 1.5 T clinical system. Echo-planar diffusion-weighted images were acquired along 64 noncollinear directions at a b-value of 1000 s mm^{-2}, along with 7 b=0 images. Reconstructed image resolution was 2 x 2 x 2 mm. Scan time was approximately 20 min.

ODFs were estimated using the Bayesian approach implemented in FSL, BEDPOSTX [3], with a maximum of two fibre populations at each voxel. Reference tracts were derived from a human white matter atlas as described in [4], represented as cubic B-splines, and transformed into the space of each subject along with the seed point. Probabilistic streamline tractography was performed by locally sampling from each fibre population—except where one population had less than a 5% estimated volume fraction—and choosing the sample whose orientation most closely matched the incoming direction (the continuity criterion) or the local orientation of the reference tract (the prior knowledge criterion). A small step of 0.5 mm was taken in the chosen direction, and then the process was repeated until the streamline was terminated due to leaving the brain or making a very sharp turn of approximately 80º or more. The probabilistic trilinear interpolation scheme described by Behrens et al. [3] was used to sample data at each step. 5000 streamlines were generated in this way, and a streamline visitation map calculated for each subject.

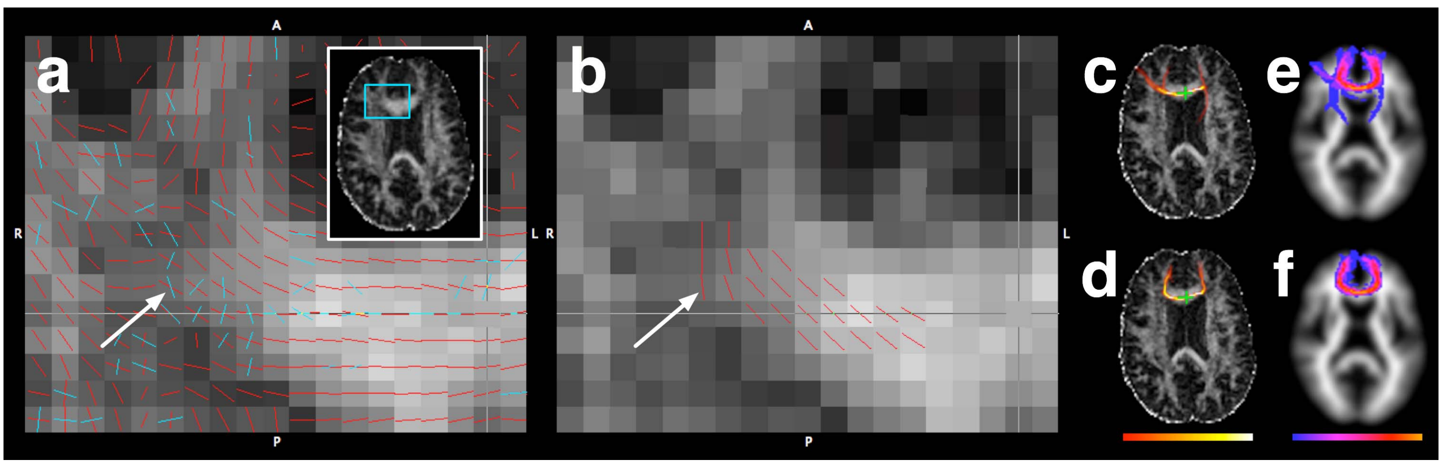

Fig. 1: *Illustration of the use of prior information to track the anterior forceps through a region of crossing fibres. (a) Mean first (red) and second (cyan) fibre population orientations in each voxel, overlaid on a map of fractional anisotropy. Crosshairs indicate the x–y position of the seed point, positioned one slice below the one shown. (b) Orientations of the reference tract for in-plane voxels visited during tracking, used to select local directions of propagation. (c,d) Maximum intensity projections of visitation maps derived from tractography performed without (c) and with (d) use of prior information in this subject. (e,f) Sum of the group's binarised visitation maps, projected into MNI standard space, without (e) and with (f) use of prior information. All visitation maps were thresholded at the 1% level.*

Results

The results of applying each method to tractography of the anterior forceps are shown in Fig. 1. The seed point in this case was in the middle of the corpus callosum genu. The arrow in subfigures 1a and 1b illustrates an example of a voxel in which continuity would tend to lead to tracking from the genu towards the right side of the brain, while the reference tract projects anteriorly at this point, in line with the expected path of the forceps. Such failures in the assumption of smoothness lead to an incoherent tracking result in this subject (subfigure 1c), whereas the prior knowledge criterion, applied in the same data, produces an appropriate representation of the forceps (subfigure 1d). Across the whole subject group, this approach produces substantially more consistent results (subfigures 1e and 1f).

Discussion

Our results demonstrate the crucial influence of careful selection amongst fibre populations when performing tractography in regions of crossing fibres. We demonstrate that a minor change to a tractography algorithm, using a population selection criterion based on prior knowledge, makes a major difference to the results produced by the algorithm. Whilst a related atlas-based approach has been described previously [5], no indication was given in that work of the consistency of results obtainable using the authors' method. Here we have demonstrated that our technique produces highly consistent results across a group of eight healthy volunteers. In future work we will examine the benefits of our approach in a range of tracts (e.g. the uncinate fasciculi and optic radiations, which include substantial curvature), and formalise it in a probabilistic modelling context.

References: **[1]** Jbabdi, S. et al., *NeuroImage* **37**:116 (2007); **[2]** Kreher, B.W. et al., *Magn Reson Med* **60**:953 (2008); **[3]** Behrens, T.E.J. et al., *NeuroImage* **34**:144 (2007); **[4]** Muñoz Maniega, S. et al., *Proc ISMRM* **16**:3318 (2008); **[5]** Xu, Q. et al., *Proc ISMRM* **17**:1447 (2009).