In vivo localisation of fibre tracts: Optimisation of fibre tracking to reduce voxel misclassification

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Introduction

There is increasing interest in applying diffusion-weighted (DW) imaging-based tractography methods in the clinic, in particular for neurosurgical planning. Much work has been done on optimisation of data acquisition protocols for diffusion tensor imaging [e.g. 1]. However, it is now becoming widely acknowledged that reliable tractography relies on the ability to resolve crossing fibres, which require more sophisticated fibre orientation estimation methods, typically based on high angular resolution DW imaging (HARDI) [2]. Optimisation in this case is more complex, as these methods typically have additional parameters that will also need to be adjusted. Moreover, optimisation strategies have so far focused on voxel-based measures, such as FA or fibre orientation. In this study, we investigate the dependence of the actual fibre-tracking results on acquisition and reconstruction parameters, by quantifying the volume of white matter incorrectly classed as belonging or not belonging to the tract.

Methods

A set of 150 DW gradient directions was generated using an ordered electrostatic repulsion method [3], designed to produce a scheme that is still near-optimal when truncated. Diffusion-weighed data were acquired using this scheme from 2 healthy volunteers on a 3T Siemens Trio system, using a twice-refocused spin-echo EPI sequence (b = 3000 s/mm^2, TE = 106 ms, 54 contiguous slices, voxel size 2.3 × 2.3 × 2.3 mm, acquisition time: ~ 21 minutes). A b=0 volume was acquired first, and after every 10 DW volume. Reduced data sets were then produced using the first N_{DW} = { 30, 45, 60, 90, 120, 150 } DW directions.

Fibre-tracking was done using the probabilistic streamlines method [4], coupled with fibre orientation distributions (FOD) obtained using super-resolved constrained spherical deconvolution (CSD) [5]. Tracking was performed using a multi-ROI approach to minimise intra- and inter-subject variability [6]: tracks were initiated from a spherical seed ROI, and only tracks that reached the target ROI were included. Tracks were terminated if they ventured outside of the white matter (using a mask generated by thresholding the FA map). Tracking was halted once the target number of tracks had been produced. Visitation maps were then generated by counting the number of tracks that entered each voxel, and thresholding at 0.1% of the total number of tracks to exclude unlikely connections. This procedure was repeated for each subset of DW directions, and over a range of harmonic orders l_{max} used for CSD (l_{max} = 6 to 14). In each case, all other parameters were kept constant, including seed & target ROIs.

To assess the quality of the tracking, a separate 'reference' visitation map was produced using N_{DW} = 150 and l_{max} = 14, as these were presumed optimal. The quantification was performed using 3 measures: the *false tract volume* (the volume occupied by voxels in the map that were not in the reference map – i.e. false positives), the *omitted tract volume* (volume occupied by voxels not in the map that were in the reference map – i.e. false negatives), and the total *misclassified volume* (the sum of the previous two measures).

In this study, two distinct white matter pathways were tracked within each hemisphere for each subject: the corticospinal tract (CST) and the optic radiations (OR), both of which are particularly relevant for neurosurgical planning. For the CST, 10,000 tracks were generated from a seed region within the CST at the base of the pons to a large target ROI encompassing the entire corresponding motor homunculus. For the OR, 2,000 tracks were generated from a seed region encompassing the lateral geniculate body to a target region encompassing both banks of the calcarine fissure.

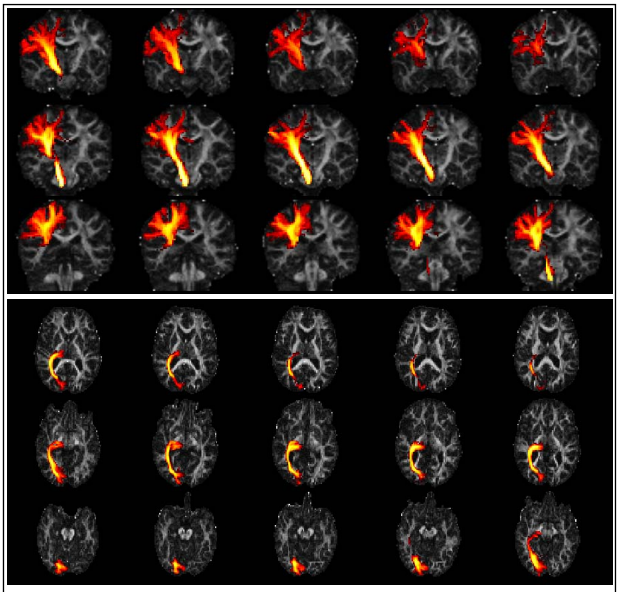

Figure 1: reference visitation maps for the left CST (top) and left OR (bottom) in one volunteer, overlaid on coronal and axial FA maps respectively. Values are displayed using a logarithmic intensity scale to aid visualisation.

Results

In all cases, the tracking methodology was able to successfully delineate the white matter pathway of interest. The CST reference tracks projected to the entire motor homunculus, and the OR reference tracks projected to both banks of the calcarine fissure (figure 1). In general, false tract volume was minimised using a high l_{max} value (figure 2a), due to the greater 'blurring' introduced in the FOD with low l_{max} values, resulting in a greater spatial extent of the estimated tracks. However, a high l_{max} value also resulted in increased omitted tract volume, especially at low N_{DW} (figure 2b), due to the increased noise sensitivity of the fibre estimation at higher l_{max} values. The total misclassified volume was reduced using higher values for both l_{max} and N_{DW} (figure 2c).

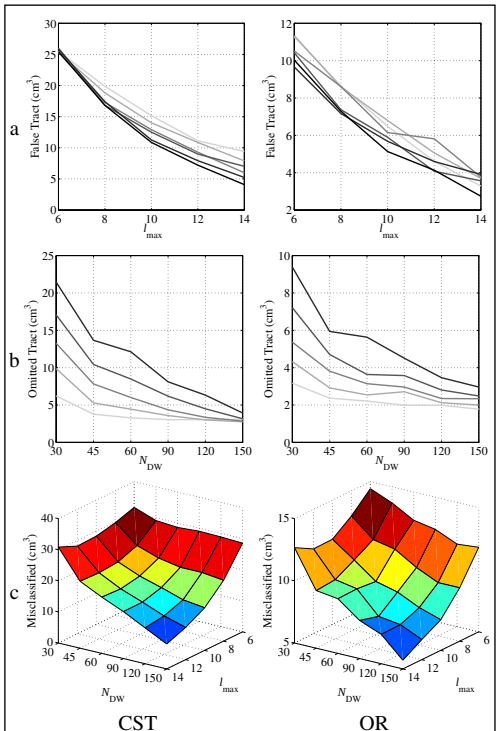

Figure 2: results for the CST (left) and OR (right), averaged over both hemisphere and both subjects. (a) false tract volume as a function of l_{max}, with N_{DW} ranging from 30 (light gray) to 150 (black). (b) omitted tract volume as a function of N_{DW}, with l_{max} ranging from 6 (light gray) to 14 (black). (c) total misclassified volume as a function of both l_{max} and N_{DW}.

Discussion

The amount of white matter misclassified as tract or non-tract is greatly reduced using a larger number of directions N_{DW} and a higher harmonic order l_{max} for the CSD reconstruction. While there are no obvious change points in figure 2c that indicate an optimal compromise set of parameters, the false tract and omitted tract measures do provide a means of tailoring the acquisition and reconstruction parameters to the particular fibre-tracking application. For example, the aim in neurosurgical planning is generally to preserve the tract of interest, in which case a low omitted tract volume is essential. This suggests that a low l_{max} value might be appropriate, but this will tend to increase the false tract volume, which may result in the surgeon being over-cautious. It may therefore be more appropriate to use a moderate value of l_{max} to reduce the false tract volume while maintaining a low omitted tract volume (e.g. using N_{DW} = 60 with l_{max} = 10). On the other hand, neuroscientific applications may favour a low false tract volume to reduce the incidence of false inferences, in which case high l_{max} values would be more appropriate.

References: [1] Jones, MRM 51: 807-815 (2004). [2] Behrens *et al.*, Neuroimage 34: 144-155 (2007). [3] Dubois *et al.*, MAGMA 19: 134-143 (2006). [4] Behrens *et al.*, MRM 50: 1077-1088 (2003). [5] Tournier *et al.*, Neuroimage 35: 1459-1472 (2007). [6] Heiervang *et al.*, Neuroimage 33: 867-877 (2006).