Automatic Segmentation of White Matter Pathways by Application of a Region Growing Algorithm

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Introduction

Fibre tracking techniques provide methods for generating white matter pathways from diffusion tensor images (DTIs). However, current techniques involve determination of regions of interest (ROIs) through which tracks must pass to be retained by the algorithm (1,2). White matter pathway generation is therefore limited by inter and intra-rater variability in ROI placement. Here we present the first fully automatic technique for segmentation of white matter pathways from DTIs throughout the entire brain. The technique removes the need for ROI definition and involves automatic determination of pathways from automatically generated single seed points by application of a novel region growing algorithm (RGA) that analyses track start and end points, track length and mean track orientation parameters. The algorithm is applied to a mean image of ten normalised subjects, from which a white matter atlas of the whole brain is generated.

Methods

MRI Data Acquisition: Ten healthy right-handed subjects were scanned on a 1.5T General Electric Signa MRI system with maximum field gradient strength 22mTm^{-1}. Diffusion tensor imaging was achieved using a single shot echo planar sequence with 12 diffusion sensitised directions as described previously (3). Whole brain coverage was achieved with two interleaved acquisitions comprising 25 slices each. In plane resolution was 2.5mm and through plane resolution was 2.8mm, providing near isotropic voxels. Each subject's DTI was normalised by affine transformation using the method of Alexander et al., (4), thus preserving the orientation of the tensor field. A normalised mean DTI was then computed (2).

Fibre Tracking: Subvoxel principal direction tracking was performed by interpolation of the tensor field as described previously (5). Tracking was initiated from the centre of every voxel in the normalised mean DTI for an FA above 0.08 and a vector step length 0.8mm with no angular threshold. For each voxel ten parameters were computed. These were the origin (o_x, o_y, o_z) and termination (t_x, t_y, t_z) points of the track, the track length (l) and the mean absolute value of the principal eigenvector direction along the track (p_x, p_y, p_z). These parameters were computed at every voxel in the brain and were stored as ten separate images.

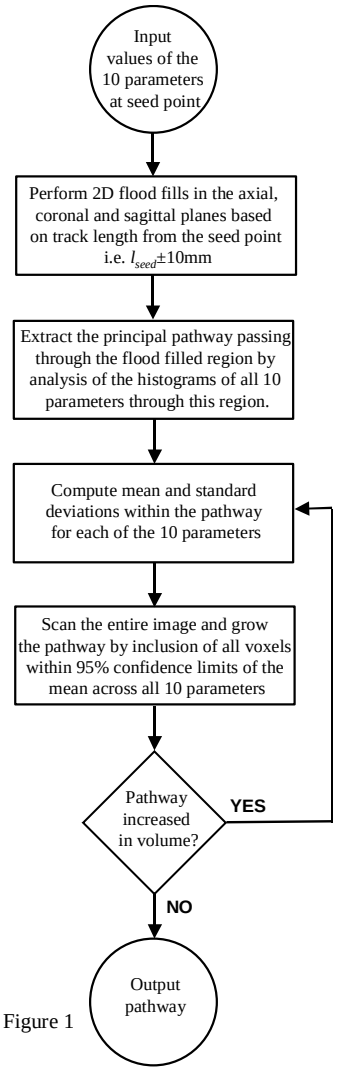

Figure 1

Region Growing Algorithm (RGA): Pathways were grown from initial seed points (voxel centres) by application of a region growing algorithm (RGA, see flow chart in Figure 1). Seed points for the RGA were automatically determined from the track length image. In particular, the rate of change of track length (i.e. the length gradient) was computed across the whole brain and voxels with low length gradients were seeded before voxels with higher gradients. By firstly seeding the RGA from voxels located far from large length gradients the white matter pathway properties were initially well defined. The RGA was also incorporated into a pathway clustering algorithm. Pathways computed independently by the RGA were merged if the mean and standard deviations of each pathway were within 95% confidence limits across all 10 parameters. The clustering algorithm was begun in an axial slice through the brainstem and proceeds from inferior to superior across the whole brain. Output from the procedure provides an image in which colours represent the centre of voxels that should be tracked from in order to reconstruct segmented white matter pathways from the analysed DTI (e.g. Figure 2c).

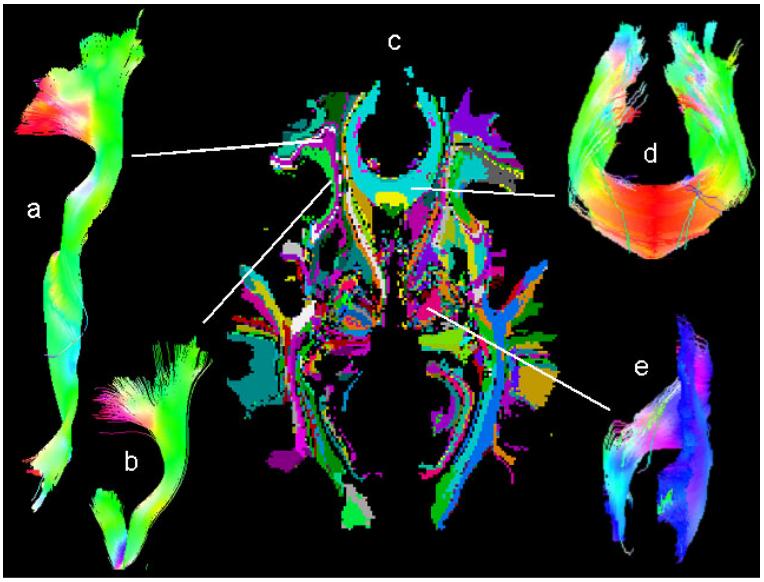

Figure 2

Results

Seed voxels for white matter pathways were automatically generated throughout the entire brain and are illustrated in Figure 2c for the axial slice below the splenium of the corpus-callosum. Coloured voxels in Figure 2c represent pathways segmented by the clustering algorithm and were verified by an experienced neuroanatomist (INL). Several of these pathways are reconstructed in Figures 2a & b and 2d & e. These include the inferior fronto-occipital (Figure 2a), and uncinate (Figure 2b) fasciculi, the forceps minor (Figure 2d) and ascending fibres to the motor and association cortices (Figure 2e). All reconstructed pathways are oriented as they appear in axial projection and are coloured according to their orientation (left to right: red, anterior to posterior: green, inferior to superior: blue).

Discussion

An algorithm has been presented to automatically segment white matter in the human brain and has been applied to generate a brain atlas of white matter pathways in ten healthy subjects. The region growing algorithm used 95% confidence limits based on 10 tracking parameters to identify and merge fibre pathways in order to generate a whole brain segmentation from which 3D white matter pathways were reconstructed. Crucially, the algorithm removes the need for time consuming generation of user-defined ROIs and also removes errors arising from inter and intra-rater variability in ROI placement. Furthermore the technique has the potential to segment DTIs of individual subjects and may be capable of determining white matter pathways in the presence of degeneration or atrophy.

References

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