Atlas Based Segmentation of White Matter Tracts of the Human Brain using Diffusion Tensor Tractography and Comparison with Classical Dissection

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Introduction and synopsis

The technique of diffusion tensor tractography is gaining increasing prominence as a non-invasive method for studying the architecture of the white matter pathways in the human brain. Numerous studies have been published that attempt to identify or reconstruct particular pathways of interest. An atlas or map of all the pathways in the white matter would be particularly useful for providing detailed anatomical data that is not available in studies based on conventional MRI data. In this study we present a method of constructing a white matter atlas which, rather than using a region of interest based approach to define structures from diffusion tensor tractography, makes use of the locations of the anatomical terminations of individual streamlines that pass through white matter. We show how a map of unique seed regions can be used to generate tracts of interest. This approach provides anatomical information that can be rapidly applied to MRI datasets for the clear identification of white matter tracts. We show close correspondence of the tracts generated from the atlas with tracts isolated with classical dissection of post-mortem brain tissue.

Methods

MRI data acquisition: 15 healthy males were scanned on a 1.5T GE Signa MRI system (maximum field gradient strength 22 mTm^{-1}). Diffusion tensor imaging (DTI) was achieved using a single shot echo planar sequence with 12 diffusion sensitised directions. Two interleaved acquisitions comprising 25 slices each provided whole brain coverage (resolution: in plane 2.5mm; through plane 2.8mm). Each subject's DTI was normalised to standard space by affine transformation (1).

Post-hoc tractography: Subvoxel streamline tractography was performed as described previously (2). Streamlines (vector step length 1.0mm, termination criteria FA < 0.08) were initiated from the centre of every voxel in the normalised DTI dataset.

Atlas construction: Step 1: A map of cortical regions (labels) was constructed based on the maps of Duvernoy (3) by an experienced neuroanatomist (NL). These labels were then mapped onto the termination locations of the streamlines obtained from whole brain tractography. Each gyrus was divided into either one, two or three regions. *Step 2*: Subcortical regions were then extended to include seed voxels within 8 mm of the nearest streamline termination voxels. Every region was given an arbitrary ordinal code, loosely based on proximity to sensory or motor regions, that allowed the regions to be ranked. *Step 3*: The mean normalised DTI was segmented into white matter tracks. Every seed voxel that gave rise to a streamline was assigned a number that combined 4bit labels of its two termination voxels in the sequence determined by their relative ranks given by their ordinal codes. *Step 4*: Where two neighbouring regions gave rise to two tracks with a similar course, similar length and similar path, the possibility of reassigning the relevant termination voxels of one region to its neighbour was considered. Termination voxels were reassigned if this did not fragment the smaller region into incoherent or non-contiguous parts. Thus region boundaries began as user-defined extrapolations from conventional atlases, but were refined by the tracks they generated. Maps of the final regions used to generate white matter tracts are shown in figure 1 with the cortical regions shown (top and middle row) and the seed regions that generate the white matter tracts (bottom row).

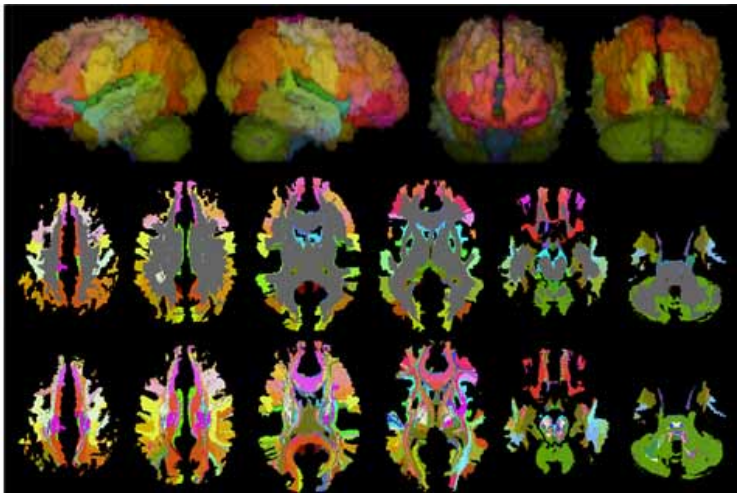

Figure 1

Classical dissection: Brains were removed from bodies embalmed with 10% formalin. Grey matter was removed from the cerebrum to expose the underlying white matter. Planes of cleavage were identified in the white matter and tracts isolated by blunt dissection using spatulas of 3mm or 6mm width. Care was taken to avoid transecting axons. A number of association tracts were studied. We focus here on the occipito-frontal fasciculus.

Results

The similarity between the inferior occipito-frontal fasciculus extracted by our tractography atlas and tracts dissected from an actual brain is shown in figure 2. At (a), the yellower colour in the tractography image corresponds to a change in direction that is indicated by the light reflecting off the dissected tract, which indicates a similar curvature of the streamlines and axons. At (b), both narrow down to an isthmus. At (c), both contain a sharply curved bend. At (d), the blue colour indicates more vertical streamlines and the dissection shows more vertical fibres. At (e) and (f), large collections of streamlines correspond to collections of fibres in the dissection. At (g) a smaller bundle of fibres in the dissection corresponds partly to a larger collection of streamlines in the tractography image. The only major difference is that the dissection breaks off before the termination of the tract anteriorly. It should be noted that the sharply angled region at (c) is in fact a section of the underlying visual radiation (Meyer's loop) in both the dissection and the tractography image.

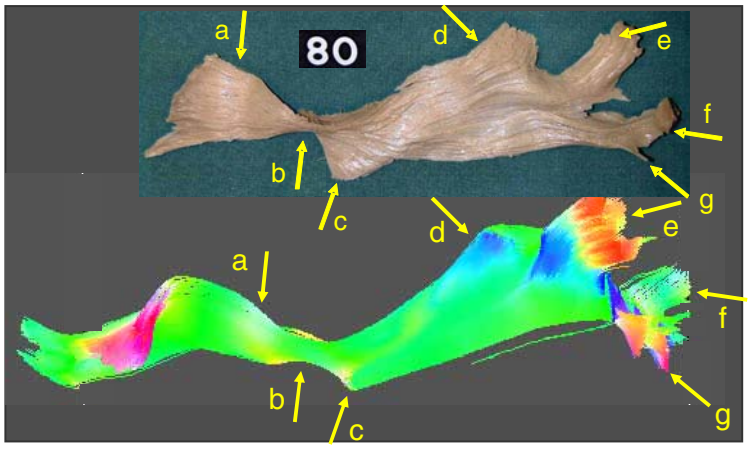

Figure 2

Discussion

We describe an image analysis technique for computation of a whole brain white matter atlas derived from a mean dataset of 15 healthy right-handed male subjects. We have shown that several association bundles (in this abstract the occipito-frontal fasciculus) segmented within our tractography atlas corresponded well with dissections from post-mortem brain specimens.

References

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[3] Duvernoy, H.M., 1999. The human brain: Surface, blood supply and three-dimensional sectional anatomy. 2nd Edition Springer Wien NewYork.