A Digital White Matter Atlas of the Rhesus Macaque Brain

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Introduction: Regional brain atlases on standardized templates are valuable for labeling neuroanatomy and defining regions of interest (ROIs) for standardized brain analyses, especially in population studies. Digital atlases with delineated brain regions have been generated for the human brain (e.g., Harvard-Oxford[1], JHU[2], MNI[3], etc.). Although rhesus macaques are a great model for investigations of neuroanatomy and models of brain-behavior relationships, there are no standardized templates of white matter anatomy in this species. Using diffusion tensor imaging (DTI) and tractography, WM structures can be identified in various ways. All of these are done by hand and are time-consuming. The overall WM can be identified by automated segmentation based on scalar DTI measures (such as fractional anisotropy (FA), principle eigenvectors, and radial diffusivity (RD)), but the separate structures cannot. In order to develop an automated method for identifying these structures we seek to create a universal atlas. In this study, we generated an atlas of white-matter (WM) structures in the rhesus macaque in order to facilitate atlas-ROI based computational pipelines for statistical analysis of the data from the specific regions.

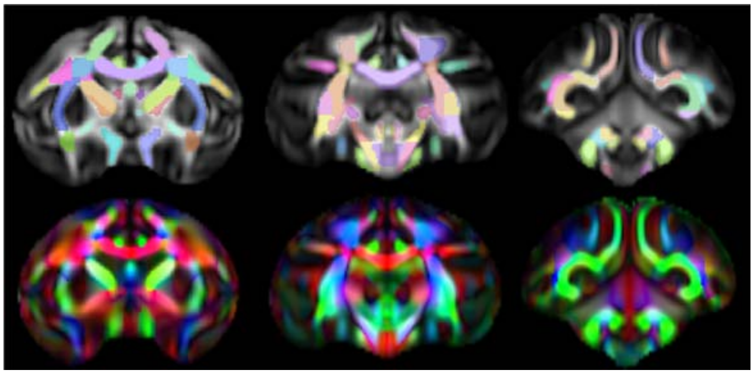

Figure 1: Top: FA maps of select slices of template (anterior on left, posterior on right) with atlas ROIs overlaid. Bottom: Color FA map of matching slices, showing delineation between tracts.

Methods: A publicly available high quality rhesus DTI template[4] created from 271 individual DTI scans (UWRMAC-DTI271) was used for generating the parcellations. The template is in the standard SL[5] space with a high spatial resolution of 0.5*mm* X 0.5*mm* X 0.5*mm*.[2] Since the anatomy of monkey and human brain white matter is qualitatively very similar,[4] we used a very carefully delineated and widely used white matter atlas from Johns Hopkins University[3] as a guide. The advantage of tracing these regions on a DTI template instead of just using a fractional anisotropy (FA) template is the unique directional information offered from the RGB color-coded directional FA map obtained from the template. The color-coding is extremely useful in defining specific boundaries for the various ROIs. The basic atlas was then registered with affine transformation to a GM rhesus atlas using DTI-TK, an advanced DTI spatial normalization and atlas construction tool[6]. This was to allow overlay of the atlas with a digitized version of the Paxinos atlas to increase end-user functionality. In addition to the 48 regions presented in the JHU human atlas, we have identified additional ROIs in the brainstem after consulting the Paxinos atlas[7] and attempting to replicate tracts observed in the figures. Unlike the JHU atlas which only parcellates the deep white matter regions, the regions created on our template were expanded to cover the majority of WM in the brain. All regions were drawn in one plane (usually coronal) and repeatedly polished in the axial and sagittal planes to create a smooth and consistent 3D structure.

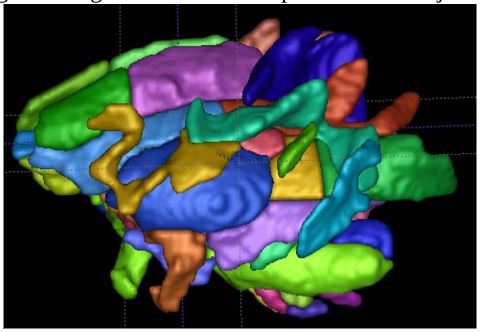

Figure 2: An oblique sagittal view of the 3D structure of atlas ROIS

Results: The atlas covers 33 separate regions in both hemispheres and 8 inter-hemisphere structures. In large structures such as the internal capsule, corpus callosum, and corona radiata, borders between sub-regions were chosen in a semi-arbitrary manner, using local FA minimums or sulcal shapes as guides where possible. In Fig. 1, several coronal slices are shown in FA images with atlas ROIs overlaid and in color maps. In Fig. 2, a 3D rendering of the atlas structures is displayed. Fig. 3 shows a slice of the atlas with a digitized version of the Paxinos atlas as an additional overlay.

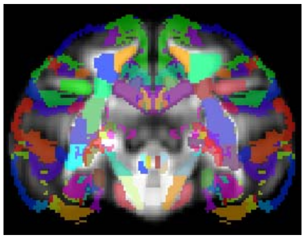

Figure 3: WM atlas and digital Paxinos atlas overlaid on template FA map.

Discussion: Because the atlas was drawn on a template created from 271 individual subjects, regions could be defined smoothly and with greater detail than the resolution of the individual scans would allow. Moreover, the atlas reflects more of a true population average in the structures of shapes, making it more applicable to studies across populations than an atlas drawn from a single subject[8] would be. Since it is in the same space as the digitized Paxinos atlas[9], the two atlases may be used together in studies interested in WM and GM, removing the need to calculate an additional warp or registration. This atlas will be made publicly available online and will serve as novel and valuable tool for the non-human primate neuroimaging community.

References: 1. Desikan RS et al. (2006) Neuroimage, 31: 968–980. 2. Hua K et al. (2008) Neuroimage, 39: 336–347. 3. Mazziotta J et al. (2001) Royal Soc Phil Trans B, 356: 1293–1322. 4. Adluru et al. NIMG, 2012. 5. Saleem KS and Logothetis NK (2007) Elsevier. 6. Zhang H et al. (2007) IEEE Trans Med Imaging 26(11):1585-1597. 7. Paxinos G et al. (2008) Academic Press. 8. Jeon T et al. (2012) 20th ISMRM 1083. 9. Moirano et al. (under review) NeuroImage.