# An Improved Population-Based Multi-Tensor Atlas of White Matter Tracts

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## Introduction

Digital brain atlases have become a fundamental tool for brain research. These atlases provide various types of anatomical information as well as a reference coordinate system for the study of pathologies [1]. Recently, Diffusion Tensor Imaging (DTI) based tractography has provided the means to trace in vivo the main white matter structures in the brain facilitating the construction of several atlases of the white matter tracts in the human brain [2,3]. These atlases, however, are limited due to the shortcomings of the DTI model and its associated tractography methods and on several tracts miss fundamental features or the whole tract itself. In this work, we present a new population-based atlas of white matter tracts based on High Angular Resolution Diffusion Imaging (HARDI). In a population of 78 healthy subjects, we use a state of the art multi-tensor tractography algorithm [4] to obtain a dense full-brain tractography and then we use dissect the major association, commissural and projection white matter tracts. Being able to trace axonal packages through areas of complex white matter anatomy, this approach enables us to consistently dissect tracts like the middle longitudinal fascicle (MdLF); the extreme capsule (EmC) [5]; the three subsections of the superior longitudinal fascicle (SLF) [6]; or the inferior ramifications of the cortico-spinal tract. Finally, we register all the tracts to MNI152 space and perform a statistical analysis to chart the shape and location of 29 white matter tracts: 11 association, 7 commissural and 7 projections ones.

## Materials and Methods

**Acquisition:** Diffusion-weighted images (DWI) from 78 healthy subjects (32.9 ± 12.4 years old of age; 64 males; right handed) were acquired at the Brigham and Women's Hospital, Boston. DWI data were acquired on a GE Signa HDxt 3.0T scanner using an echo planar imaging sequence with a double echo option, an 8 Channel coil and ASSET with a SENSE-factor of 2. The acquisition consisted in 51 directions with b=900 s/mm2, and 8 images with b=0 s/mm2, with scan parameters TR=17000 ms, TE=78 ms, FOV=24 cm, 144×144 encoding steps, 1.7 mm slice thickness. A total of 85 axial slices covering the whole brain were acquired. A structural MRI acquisition protocol was also used, which includes two MRI pulse sequences. The first results in fastSPGR with the following parameters; TR=7.4ms, TE=3ms, TI=600, 10 degree flip angle, 25.6cm2 field of view, matrix=256×256. The voxel dimensions are 1mm3. The second: XETA produces a series of contiguous T2- weighted images (TR=2500ms, TE=80ms, 25.6 cm2 field of view). Voxel dimensions are also 1mm3.

**In vivo White Matter Dissection:** For each DWI image we automatically extracted a total of N white matter structures. We started by performing a multi-tensor full-brain tractography placing ten seeds per voxel and obtaining an average of one million tracts per subject. Then, we registered the tracts to the MNI152 template using ANTS [7]. Finally, using the WMQL approach [8], we automatically extracted a total of 29 white matter structures per subject.

**Population-Based Atlasing:** Finally, we charted the shape and location of each white matter tract in the population. We generated a group effect map for each tract on MNI space. The group effect map assesses the probability that a tract traverses each voxel. For this, we rejected at each voxel the null hypothesis that such voxel is not traversed by the tract [3]. We started by calculating a binary visitation map for each tract of each subject. This map is a mask in MNI space where a voxel has a value of one if the tract traverses that voxel and 0 if it doesn't. We smoothed the visitation maps with a 2-mm (full with at half maximum) isotropic Gaussian kernel. Then, we rejected the hypothesis that the voxel does not belong to the tract, i.e. the mean traversal value over all subjects on that voxel is different to 0, by using a voxel wise t-test for a one-sample mean. We calculated the corrected significance using permutation testing (10,000 iterations) to avoid a high dependence on Gaussian assumptions [9]. We set the significance threshold for considering that a voxel belongs to the tract to p-value < 0.0001 corrected for multiple comparisons.

## Results

After obtaining the group effect maps for each tract, we calculated the iso-surface at 0.0001 p-value and reconstructed it in 3D inside of a glass brain. The results of this processing are shown in figure 1. We obtained 11 association tracts first 4 rows on the right of the figure, in blue; the 7 subdivisions of the corpus callosum (top right of the figure) stated by [9]; we also obtained the striato-cortical projections to the fronto-orbital, prefrontal, pre-motor, parietal and occipital lobes and the optical radiations.

## Discussion and Conclusion

We presented a novel population based atlas of white matter tracts in the human brain. Our atlas is based on HARDI-tractography methods enabling us to trace known white matter structures with greater detail, like the cingulate fascicles and the cortico-spinal tracts, as well as tracts not currently found on current white matter atlases like the 3 components of the SLF, the MdLF and the EmC. Further research will focus on the use of this atlas to perform population-based studies of characteristic variations of white matter structures in pathologies like schizophrenia.

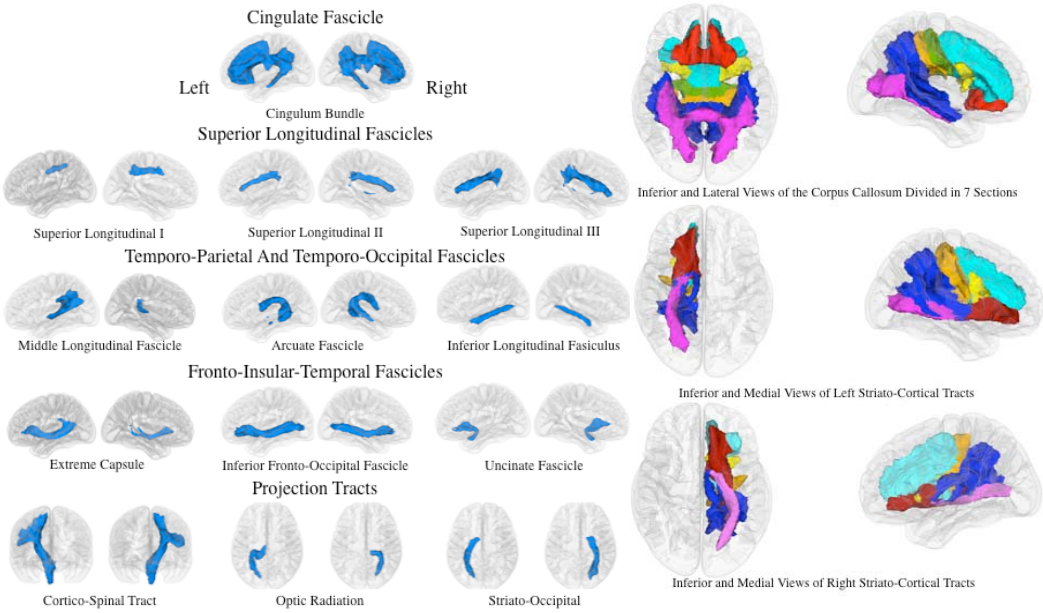


**Fig 1:** *On the left*, as blue volumes, we show the iso-surfaces at p-value = 0.0001 (corrected) corresponding to 11 Association tacts and 3 projection ones. *On the right* we show 7 subdivisions of the Corpus Callosum: fronto-orbital (red) prefrontal (cyan) premotor (green) motor (orange) parietal and superior-temporal (blue) and occipital (magenta). We also show 5 striato-cortical circuits projecting to different areas of the cortex: orbito-frontal (red), prefrontal (cyan) motor (orange) parietal (blue) and occipital (magenta).

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