

A HARDI multi-subject bundle atlas of known deep white matter and short superficial white matter tracts

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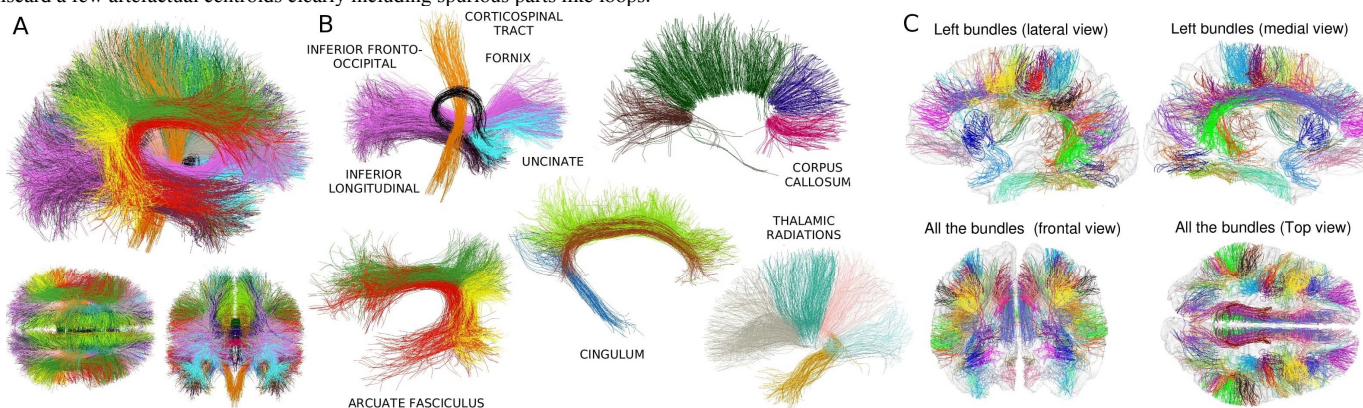
Introduction

The study of human brain connectivity is a key research area for neurosciences. In this context, diffusion MRI tractography is the preferred *in vivo* non invasive technique for the study of brain anatomical connections. Using this technique, the main deep white matter (WM) tracts have been deeply studied and several methods have been developed in order to extract these tracts in a population of subjects. Most of the methods use anatomical information embedded in atlases of gray and white matter ROI [1, 2] or another kind of fiber cluster labeling information [3]. On the other side, short association bundles of superficial WM have been rarely studied. In order to have a more complete and better description of WM tracts, we present a HARDI human brain multi-subject bundle atlas of known deep WM (DWM) and short superficial WM (SWM) tracts. The atlas was derived from a two-level intra-subject and inter-subject clustering strategy. Each atlas bundle corresponds to several inter-subject clusters labeled by an expert in neuroanatomy to account for subdivisions of the underlying pathway often presenting large variability across subjects. An atlas bundle is represented by the multi-subject list of the centroids of all intra-subject clusters in order to get a good sampling of the shape and localization variability. The atlas contains 36 DWM bundles belonging to brain hemispheres and the corpus callosum, and 47 SWM bundles in each hemisphere.

Material and Methods

Datasets. The atlas was inferred from a HARDI database of 12 healthy subjects [4], providing high quality T1-weighted and DW-weighted images acquired on a GE Healthcare Signa 1.5 Tesla Excite II system. DW data was acquired using a single-shot twice refocused spin-echo DW-EPI sequence with a b-value =3000s/mm² and 200 DW directions. DW data were corrected from susceptibility artifacts using a preliminary field map acquisition. T1 and DW-weighted data were optimally aligned using a rigid 3D transform estimated by an automatic registration algorithm based on mutual information and matched to the T1 data. Raw HARDI data was first denoised with a Non-Local Means filter adapted to Rician noise [5]. The Fiber Orientation Distribution (FOD) was then reconstructed in each voxel using a spherical deconvolution of fiber ODF [6], using a maximum spherical harmonic order 8 and a Laplace-Beltrami regularization factor = 0.006. A whole brain streamline deterministic tractography [7] was performed using this FOD field within a robust tractography mask computed from the T1-weighted data, allowing a better delineation of superficial connectivity [8]. Thalamic segmentations were obtained from T1-weighted images using an automatic segmentation tool [9].

Method. The atlas inference was performed using a two-level clustering, described in [10], with some improvements. First, intra-subject (IS) clustering [11] was applied to each dataset. This IS clustering reduces the tractography dataset information from more than one million of tracts to a few thousand fiber bundles. The obtained bundles are thin and regular fiber fascicles, composed by fibers presenting similar length and shape, that can be represented by a single fiber, called a bundle centroid. In order to get a good representation of the thalamic radiations in the atlas, an additional step uses a thalamic mask for cutting the fibers passing through these structures. The second clustering level aimed at matching the putative bundles produced by the previous level across the population of subjects. In this inter-subject clustering, fiber centroids from all the subjects were aligned by an affine transformation to the Talairach space (TS), estimated from the T1-weighted image. Then, the centroids were clustered using pairwise distance measures in order to match bundles with similar shapes and positions in TS. In order to get population representative clusters, only clusters composed by centroids from at least half of the subjects were selected. These inter-subject clusters were manually labeled by an expert in neuroanatomy in order to identify known WM tracts and a big amount of short superficial WM tracts. Anatomical information like brain surface parcellation was used in the cluster labeling process. Each atlas bundle is then represented by the complete set of individual centroids belonging to the underlying intra-subject clusters. A last visual inspection led to discard a few artefactual centroids clearly including spurious parts like loops.



Results

The inference of DWM tracts was done for the bundles of both hemispheres and the corpus callosum. The current atlas (LNAO-DWM12) includes 36 bundles, composed by 11 WM tracts in each hemisphere (arcuate (AR), inferior longitudinal, inferior fronto-occipital, uncinate, cingulum (CG), corticospinal, fornix and the thalamic radiations (TR)), and the corpus callosum (CC). Some tracts are divided into a few fascicles: AR (3 fascicles), CG (3 fascicles), TR (5 tracts) and CC (4 tracts), see the whole DWM atlas in Fig. A and DWM bundles in Fig. B. The SWM bundles were obtained for the left hemisphere (LH) and bundles of the right hemisphere were obtained using the symmetric of those of the LH with respect to Talairach inter-hemispheric plane. Ongoing work aims at performing the same inference for the RH in order to remove any bias. The current atlas (LNAO-SWM12) includes a total of 47 SWM bundles for each hemisphere (see Fig. C).

Discussion and Conclusion

We think that the created HARDI multi-subject human brain bundle atlas present several qualities. First, it was inferred from HARDI data and an improved T1-based tractography propagation mask, leading to a better description of WM bundles than preceding works. As fiber shape and position information is used for its inference, the proposed atlas allows a better decomposition of the bundles, which can be of great interest to neuroanatomists and neuroscientists. Some examples are the subdivisions of the arcuate fasciculus, the cingulum and several short association bundles. The multi-subject representation of our atlas, embedding the shape and localization variability of the bundles is a powerful tool for further analyses. It has been shown recently to be more efficient than the usual single template approach for brain structure recognition because of weaknesses of the spatial normalization paradigm [12]. An important application is the use of this atlas for the automatic segmentation of new tractography datasets [13] which leads in the case of DWM bundles to better results than a well known ROI-based method [2], and may improve the sensitivity of morphometric studies.

References

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