Basal ganglia connectivity inferred from tractography: dealing with direct and indirect connections

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Introduction

The basal ganglia (striatum and globus pallidus) participate in motor, cognitive and behavioural functions and establish different connections with each other and with the cortex. Since pioneering ex-vivo tract tracing studies [1], progress in diffusion imaging and tractography techniques has allowed studying these connections in vivo [2,3]. All previous tractography-based studies that investigated connections of the basal ganglia used seed to target regions tractography method. The problem of such an approach is that it does not separate direct from indirect connections. We present a new method for the selection of the tracts linking brain structures from a whole brain tractogram obtained using streamline tractography. This method takes into account the basal ganglia circuits and provides only the direct connections between a pair of brain regions of interest. It allows removing the effect of indirect connections from connectivity based studies. We use surface connectivity atlases [4] as an application to illustrate the impact of this new tract selection approach on the analysis of the connections between the basal ganglia and the cortex.

Material and methods

The connections between the basal ganglia and the cortex were computed on a database containing DW and T1 data from 15 healthy subjects that signed an informed consent. These subjects were part of the TRACK-HD study.

Acquisition - Data were acquired on a Siemens Tim Trio 3T MRI system. Sequence parameters were as follows: **T1-weighted 3D MPRAGE** FOV=256mm, matrix 256x256, TE/TR=2.98ms/2.3s, TH=1.1mm, Phase FOV=93.8%, 160 slices per slab, RBW=240Hz/pixel; **Single-shot twice refocused spin-echo DW-EPI** FOV=256mm, TH=2mm, matrix 128x128, TE/TR=86ms/12s, GRAPPA 2, partial Fourier 6/8, 80 slices, RBW=1630Hz/pixel, b-value =1000s/mm², 50 directions; DW data were corrected from susceptibility artifacts using a preliminary field map acquisition and matched to the T1 data.

Preprocessings - For each subject, an Orientation Distribution Function (ODF) field was computed using the analytical Q-ball model of [5]. A whole brain streamline probabilistic tractography [6] was performed using this ODF field within a robust tractography mask computed from the T1-weighted data [7] and registered to the DW data. Deep nuclei segmentations were obtained from T1-weighted images using an automatic segmentation tool (BrainVISA/Nucleist [8])

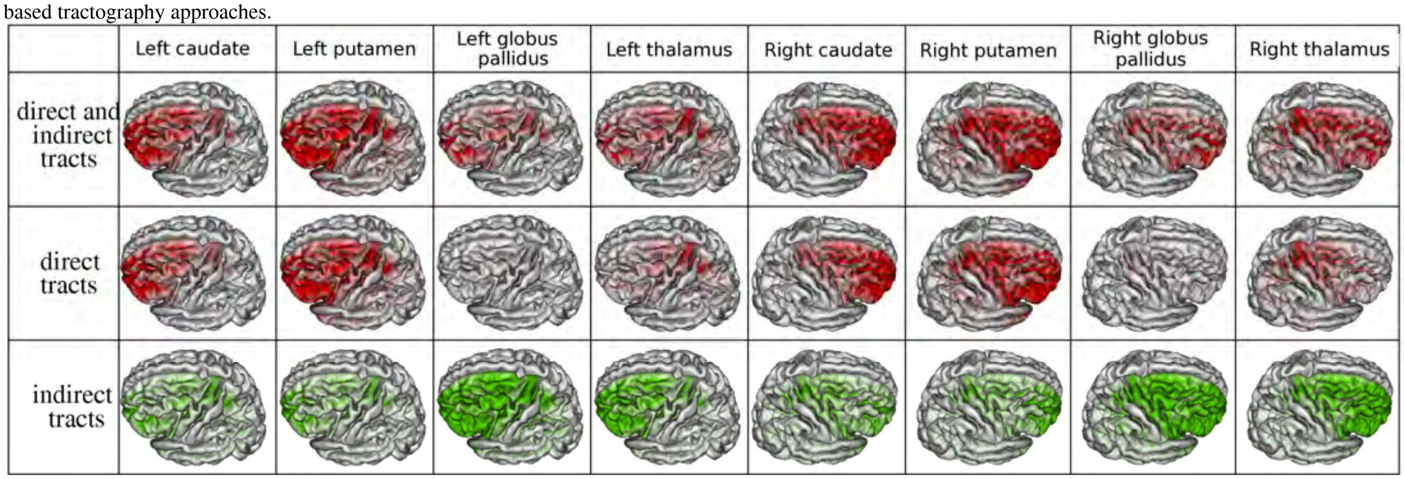
Tract selection procedure - From the obtained whole brain tracts, the tracts linking each nucleus to the cortex were selected. In order to highlight the importance of differentiating direct tracts from indirect ones we used two procedures to select the tracts. 1) The first procedure consisted in computing the intersection between each tract and both the cortex and the nucleus of interest. This procedure has the disadvantage of mixing direct and indirect tracts; which is also the case in the ROI based classical tractography approaches. 2) The second procedure consisted in computing the intersection between each tract and all the structures (cortex, nucleus of interest and other basal ganglia). For each nucleus of interest, only the portions of tract that constitute a direct path between the nucleus and the cortex were kept.

Surface connectivity atlases - Surface connectivity atlases were computed between each nucleus and the cortex using the tracts selected for each nucleus and by computing the intersection between these tracts and the cortex as described in [4]. We compared the surface connectivity atlases obtained from the tracts computed using both selection procedures.

Results and discussion

The obtained surface connectivity atlases are shown in the figure below for three basal ganglia nuclei (caudate nucleus, putamen and globus pallidus) and the thalamus. The first and the second lines represent the surface connectivity atlases obtained using the tracts selected with the first and the second procedure respectively. The third line depicts with a green gradient palette the difference between the connectivity atlases of the first and the second line.

It shows the indirect connections of each nucleus to the cortex. For the globus pallidus when the striatum and thalamus are not taken into account in the tract selection process, connections between the pallidum and the cortex are obtained (direct and indirect connections), which correspond to connections going through other intermediate nuclei (indirect connections) as this structure is not directly connected to the cortex (no direct connections). This is what also happens when using classical ROI based tractography approaches.



Conclusion

We presented a new method for the selection of tracts linking two brain structures which provided direct connections and removed indirect ones. We showed the importance of adding a priori knowledge when studying the anatomical connectivity, for instance, in this example by taking all the deep structures into account in the tract selection process and its impact on the computation of surface connectivity atlases. Even though the results of the method that we proposed were illustrated using a streamline probabilistic tractography algorithm; the idea of taking all nuclei into account in the analysis of the connectivity between two given structures should be generalized to any other study focusing on the connectivity of the basal ganglia.

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