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Delineation of the Globus Pallidus Pars Interna and the Subthalamic Nucleus Pathways in Patients with Parkinson's Disease Selected for Deep Brain Stimulation: Comparison of Deterministic and Probabilistic White Matter Fiber Tractography

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Introduction

Deep brain stimulation (DBS) is effective in improving motor symptoms for patients with advanced Parkinson's disease (PD) through high-frequency stimulation to the subthalamic nucleus (STN) and globus pallidus interna (GPi) [1,2]. The purpose of this study is to (1) evaluate and compare pathways and associated STN and GPi generated by two different diffusion tensor tractography methods: a tensor-based deterministic method, and an advanced probabilistic method and (2) determine a reliable tractography method for use in high-precision stereotactic surgery.

Results

Deterministic and probabilistic cortico-subthalamic and cortic-globus pallidus tracts were successfully reconstructed for all subjects across all STNs (left and right) and GPis (left and right) (figures 1 and 2). The variability between proposed techniques was shown using center of mass coordinates across all patients for both GPi and STN.

As shown in table 1, the distance between the center-of-gravity coordinates of the two methods ranged from 0.16-13.85 mm (mean 1.71 mm, Std 2.56 mm).

Methods

A total of 7 patients selected for DBS aged 69-78 years were included and scanned in a 3.0T Philips Achieva MR scanner. DTI images were acquired axially in the same anatomical location prescribed for the T1-weighted images. DTI images initially were corrected for eddy current distortion and motion induced artifacts. To generate STN and GPi pathways the brain cortical surface was segmented based on T1-weighted images using Freesurfer. The anterior and posterior primary motor areas and pre-motor area were selected as cortical seeds. GPi and STN were segmented manually and then co-registered to the DTI space. Fiber assignment of probabilistic and deterministic tractography was performed using the combined motor areas as initiation seeds and the STN and GPi as the inclusion mask.

Table 1

	Center-of-Gravity Coordinates			
Case No.	deterministic	probabilistic	Euclidean Distance (mm)	DSC
1				
STN L	62.1, 69.76, 25.5	62.2, 69.7, 25.5	0.16	1.00
STN R	62.9, 56.3, 25.5	62.7, 56.1, 25.5	1.16	1.00
GPi L	63.1, 74.9, 39.5	63.1, 74.6, 29.5	1.21	0.87
GPi R	62.7, 50.7, 28.0	62.8, 50.9, 28.0	0.85	0.66
2				
STN L	54.8, 70.5, 39.0	54.8, 70.6, 39.0	0.30	1.00
STN R	55.9, 57.7, 39.0	55.82, 57.6, 39.0	0.67	1.00
GPi L	57.2, 74.9, 42.5	57.5, 74.0, 42.5	4.31	0.63
GPi R	59.5, 54.5, 42.5	59.0, 54.2, 42.5	2.20	0.83
3				
STN L	63.3, 71.6, 35.0	63.6, 71.2, 35.0	2.23	1.00
STN R	62.2, 58.9, 34.5	62.2, 58.9, 34.5	0.17	1.00
GPi L	66.4, 74.2, 37.5	68.8, 72.0, 36.5	13.85	0.29
GPi R	64.3, 55.3, 38.0	64.9, 55.9, 38.0	3.21	0.80
4				
STN L	59.1, 70.8, 39.5	59.0, 71.1, 39.5	1.07	0.94
STN R	60.1, 58.0, 40.5	60.1, 58.0, 40.5	0.41	1.00
GPi L	61.6, 75.3, 43.0	61.4, 75.1, 43.0	1.08	0.59
GPi R	62.8, 53.8, 45.0	62.8, 54.1, 45.0	1.15	0.63
5				
STN L	64.5, 70.8, 34.0	64.8, 70.5, 34.0	1.81	1.00
STN R	63.0, 56.9, 34.0	63.4, 57.1, 34.0	1.59	1.00
GPi L	64.5, 75.0, 38.5	64.8, 74.8, 38.5	1.55	0.83
GPi R	65.4, 53.8, 40.0	65.8, 54.2, 40.0	2.18	0.80
6				
STN L	62.5, 70.5, 38.5	62.4, 70.5, 38.5	0.23	1.00
STN R	62.4, 57.4, 38.5	62.1, 57.1, 38.5	1.66	1.00
GPi L	64.7, 73.9, 41.0	64.8, 73.7, 41.0	0.85	0.71
GPi R	64.9, 53.1, 41.0	64.5, 52.9, 41.0	1.56	0.78
7				
STN L	64.4, 69.1, 40.0	64.3, 69.1, 40.0	0.48	1.00
STN R	64.7, 57.3, 41.0	64.7, 57.2, 41.0	0.16	1.00
GPi L	68.3, 70.4, 44.5	68.1, 70.3, 44.5	0.77	0.76
GPi R	65.1, 53.4, 44.0	65.3, 53.6, 44.0	0.99	0.80
			Mean= 1.71	
			Std= 2.56	

Table 1: Difference in target regions center-of-gravity coordinates between tractography methods.

Figure 1

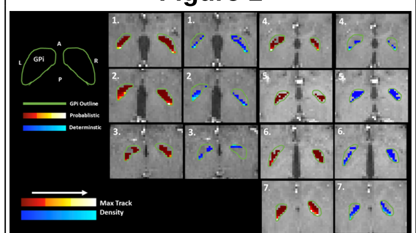

Figure 1. Cross sectional view of probabilistic and deterministic tract density maps of direct cortico-GPi pathways within GPi segment (left and right). Condensed cortico-GPi pathways have been shown in the medial posterior portion of the GPi.

Conclusions

Our results revealed a higher condensed pathway in the dorsolateral portion of the STN and medial posterior side of the GPi. The averaged distance between center of mass coordinates of the two techniques showed bigger divergence in GPi than in the STN. These differences indicate probabilistic tractography as a more robust method for accurate DBS electrode placement, where better targeting will lead to better patient treatment and outcomes.

Learning Objectives

To delineate three pathways involved in the mediation of DBS treatment effects: the hyperdirect, direct and indirect pathways. As our knowledge, this is first study not only reconstructed cortico-STN hyperdirect pathways but also direct and indirect cortico-GPi pathways with the feasibility in clinical applications.

References

[1] Schlaier, J. R., Beer, A. L., Faltermeier, R., Fellner, C., Steib, K., Lange, M., ... & Anthofer, J. M. (2017). Probabilistic versus deterministic fiber tracking and the influence of different seed regions to delineate cerebellar-thalamic fibers in deep brain stimulation. European Journal of Neuroscience.

[2] Petersen M. V, Lund T. E, Sunde N, Frandsen J, Rosendal F, Juul N, Ostergaard K. Probabilistic versus deterministic tractography for delineation of the cortico-subthalamic hyperdirect pathway in patients with Parkinson disease selected for deep brain stimulation, Journal of neurosurgery, 2015; 1-12.

Figure 2

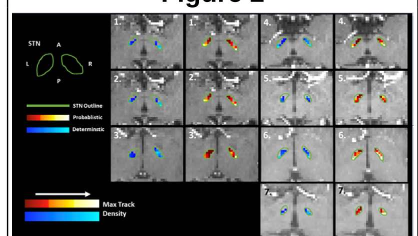

Figure 2. Cross sectional view of probabilistic and deterministic tract density maps of hyperdirect cortico-subthalamic pathways within STN segment (left and right). Condensed cortico-STN pathways have been shown in the dorsolateral portion of the STN.