Topological changes of the brain functional network during performance of self-initiated movement in PD patients

Xiaojun Xu[1], Dan Long[1], and Minming Zhang[1]

[1]*Department of Radiology, Second Affiliated Hospital, Zhejiang University School of Medicine, Hangzhou, Zhejiang, China, People's Republic of*

Introduction

Patients with Parkinson's disease (PD) have difficulty in performing self-initiated movements. The ability to initiate movements, particularly those that are internally generated or sequentially structured, is a function of the premotor areas in the medial wall of the frontal lobe including the supplementary motor area (SMA) [1]. In PD patients, functional imaging with tasks requiring motor initiation identified defective activation of the SMA [2]. Although the relationship between the dysfunction of SMA and the defect of self-initiated movements in PD patients has been well established, little has been known about how the dysfunction of SMA affected the whole functional network during movement. In this study, we used fMRI and complex network analysis based on graph theory to investigate the topological changes of the brain networks during performance of self-initiated movement in PD patients.

Materials and Methods

fMRIs were acquired in 17 PD patients and 19 age-matched normal controls, when performing a self-initiated finger-thumb opposition task. Imaging was performed using a whole-body 1.5T Signa GE scanner. A series of preprocessing steps common to most fMRI analyses was conducted using the SPM8 software. After the preprocessing, a two-sample t-test was used to detect the activation differences between patients and normal controls. Compared with the patients, control group showed significant activation in the right SMA ($p<0.005$, uncorrected). The time series of BOLD signal change in the right SMA was extracted and correlated with that from other brain regions. The voxel with the correlation coefficient survived from a correction for multiple comparisons using a false discovery rate of 0.1% as a threshold was reserved. All clusters with at least 10 contiguous such voxels constituted the SMA-related functional network. Each cluster was considered as a node in the network. Then, the mask of the constructed network was copied to each subject. Mean time-series from each node were de-correlated for movement parameters and cross-correlated to construct a correlation matrix. In the matrix, the correlation coefficient represented the functional connectivity strength between any two nodes in the network. Each correlation matrix was thresholded into a binarized matrix with a wide range of sparsity (30%-50%) at the interval of 0.01. Finally, network parameters of each subject were calculated from the connectivity matrices and compared between the patient and control group. Normalized clustering coefficient (γ), normalized shortest path length (λ), global efficiency (E_{glob}), and local efficiency (E_{loc}) were calculated to determine the global characteristics of the SMA-related functional network. Nodal degree (K_i), nodal efficiency (E_{nod}) and nodal betweenness centrality (N_{bc}) of each node were calculated and integrated into a normalized nodal parameter χ_{norm} to determine the hub of the functional network.

Result

The SMA-related functional network consisted of 19 nodes which mainly located in the frontal lobe, occipital lobe and the limbic system (Table 1). There was no significant difference on the global network parameters (γ, λ, E_{glob} and E_{loc}) between the PD patients and normal controls. However, the hubs of these two networks were different (Fig 1). In the normal controls, the hubs were the right SMA, the left hippocampus, the left posterior cingulated and the right precuneus. In the PD patients, right SMA was no longer the hub, whereas left middle occipital gyrus and the right superior occipital gyrus were new hubs of the function network.

	Structure	BA	MNI coordinate		
			x	y	z
L	Lateral Globus Pallidus		-12	3	0
R	Precuneus	BA7	12	-51	48
R	Fusiform	BA20	30	-22	-33
L	Superior Frontal Gyrus	BA11	-15	54	-15
L	Middle Frontal Gyrus	BA11	-30	42	-12
R	Hippocampus		33	-27	-6
L	Hippocampus		-27	-33	-6
L	Inferior Frontal Gyrus	BA47	-54	33	-3
R	Hippocampus	BA27	24	-33	-3
L	Middle Occipital Gyrus	BA18	-27	-87	0
L	Medial Dorsal Nucleus		-6	-15	6
L	Inferior Frontal Gyrus	BA13	-42	24	9
L	Middle Frontal Gyrus	BA46	-36	36	15
L	Middle Occipital Gyrus	BA19	-27	-81	15
L	Posterior Cingulate	BA23	-3	-39	21
L	Superior Frontal Gyrus	BA10	-21	45	27
R	Superior Occipital Gyrus	BA19	36	-75	24
L	Precentral Gyrus	BA6	-39	0	30
L	Middle Frontal Gyrus	BA9	-27	30	36

Table 1. the SMA related functional networks during during performance of self-initiated movements.

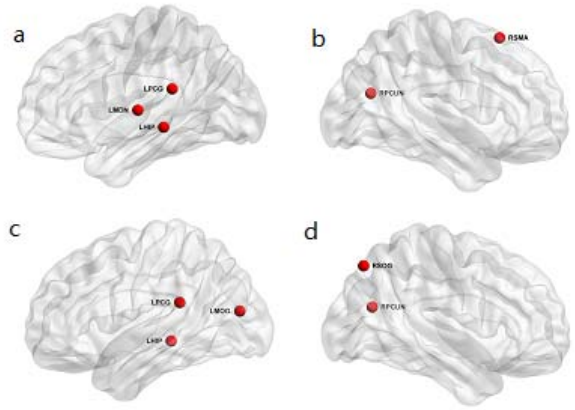

Fig 1. The hubs in the SMA related functional networks. Regions with any normalized nodal parameter X_i (X is D_{nod},E_{nod},or N_{bc}) greater than mean X_i + SD(X_i) were identified as hubs. (a)and (b) controls group; (c) and (d) patients group,

Conclusion

Our study demonstrated the topological changes of the brain networks during performance of self-initiated movement in PD patients. Right SMA lost its importance in the function network in PD patients, which may reflect the dysfunction of SMA and account for the defect of self-initiated movements in PD patients. The increase of the importance of left middle occipital gyrus and the right superior occipital gyrus in the network may play a compensatory role in the dysfunction of SMA.

References:

1. Tanji J, Hoshi E. Curr Opin Neurobiol 2001, 11: 164-170.
2. Grafton ST. Curr Opin Neurobiol 2004, 14: 715-719.