Connective Fiber Tracts in Default Mode Network Mapped by Resting State fMRI and Diffusion Spectrum Imaging

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Introduction

It has been found that the low frequency fluctuation of blood oxygen level-dependent (BOLD) signal in the resting-state fMRI showed temporal correlations between widely separated cortical regions [1]. The temporal correlations are considered to reflect the functional connectivity of thoughts, intended speech, and emotion [2, 3]. The cortical regions involved in the network include posterior cingulum cortex (PCC)/retropslenial cortex (RSC), medial prefrontal lobe (MPFC) and medial temporal lobes (MTLs). These regions are considered the brain default mode network (DMN). The cortical regions of DMN are characterized by being deactivated during attention-demanding tasks. Axonal fiber tracts between nodes of the DMN have been identified in macaques by tract-tracing techniques, such as monosynaptic connections between MTL and (PCC/RSC) [4]. Using diffusion tensor imaging (DTI) tractography, Greicius *et al.* first demonstrated *in vivo* two fiber tracts in DMN [5]. They found one tract connecting MPFC and PCC, and the other tract connecting RSC and MTLs. A complete structural connectivity of the whole DMN, however, is still lacking. The long-range fibers connecting the cortical regions in DMN may encounter fiber crossing with other intersecting fibers, making reconstruction of fiber tracts between these regions challenging. Therefore, in this study, we aim to use diffusion spectrum image (DSI) tractography to map structural connectivity between resting-state fMRI cortical areas in the DMN.

Materials and Methods

Subjects Four right-handed adults were recruited in the study (2 males and 2 females; age mean: 22.25 ± 1.6 years; mean Edinburg Inventory score = 100 ± 0.0). ***Data acquisition*** All images were acquired on a 3T MRI system (Trio, Siemens, Erlangen, Germany). The acquisition protocol included (1) the resting-state fMRI with gradient echo EPI, (2) DSI with spin-echo diffusion EPI, and (3) trans-axial T2-weighted (T2W) images using a turbo spin echo sequence (See details in Table 1 for imaging parameters). ***Data Processing*** Resting state fMRI Images were first co-registered with the T2W images then normalized to a T2W MNI template. The normalized images were spatially smoothed with a Gaussian kernel with FWHM = 4mm. All the preprocessing were performed by SPM5 (Wellcome Department of Imaging Neuroscience, London). The regional homogeneity (Reho) maps of resting-state fMRI were analyzed by REST [6]. Reho analyzed the temporally similarity between the time course of a voxel and its neighbors in a voxel-wise fashion, and detected the voxel clusters which manifested functional coherence during fMRI scan. The group-averaged Reho maps were obtained by performing one-sample t-test on the whole brain thresholded at a significant level $p<0.0001$ and selecting clusters with sizes bigger than 64 voxels. The significant regions on the Reho maps were used as regions-of-interest (ROIs) in the DSI tractography. DSI tractography DSI analysis was performed based on the Fourier pair between the echo signal $S(\mathbf{q})$ and the diffusion probability density function $P(\mathbf{r})$ [7]. The orientation distribution function (ODF) was determined by computing the second moment of $P(\mathbf{r})$ along each radial direction. A decomposition method was used to decompose the original ODF into several constituent ODFs, representing the orientations of individual crossing fibers [8]. Tractography was reconstructed based on a simple algorithm adapted for DSI data. One of the decomposed fiber vectors in the white matter pixels was used as a seed vector to produce one fiber tract. A step of 0.4 pixel was tracked forward from the seed vector, and all vectors in the nearest voxels were evaluated to determine the proceeding orientation for the next step. A vector with closest orientation to the starting vector was chosen if it was within 45° deviation. Tracking stopped if no such vectors were found in the nearest voxels. The procedure of the fiber tracking was iterated by randomly selecting the seed vectors in the white matter pixels. The ROIs obtained from the Reho maps revealed bilateral PCC/RSC, MPFC and MTLs, and these ROIs were used to select the fiber tracts that passed through any pair of the ROIs. No structural connection was considered if there was no fiber tract connecting any of two ROIs after 100,000 iterations.

Results

We found that there were tracts connecting every pair of ROIs in DMN, but there was no tract passing through three ROIs simultaneously. The MPFC and PCC/RSC were connected by cingulum bundles. The PCC/RSC and MTL were connected in part by inferior longitudinal fasciculus (ILF) and by inferior fronto-occipital fasciculus (IFOF). Bilateral MTLs were connected by tapedum of corpus callosum. The MPFC and bilateral MTLs were connected by two different tracts, namely, stria terminalis and medial forebrain bundle. Tract between bilateral PCC/RSC is splenium of corpus callosum and tract between bilateral MPFC is genu of corpus callosum.

Conclusions

Using DSI and resting state fMRI, we have demonstrated the structurally connective fiber tracts in DMN. These tracts were found to involve the pathways of the limbic system on each hemisphere and commissural fibers connecting bilateral hemispheres.

	Resting state fMRI	DSI	T2-weighted imaging
FOV (mm)	220	370	250
TR/TE (ms)	2000/30	9100/142	5920/102
Matrix size	64×64	128×128	256×256
Slice number	34	45	34
Slice thickness (mm)	4	2.9	3.9
Voxel size (mm)	3.4×3.4×4.0	2.9×2.9×2.9	1×1×3.9
bmax-value (s mm^{-2})	N/A	4000	N/A
Diffusion encoding number	N/A	203	N/A

Table 1. MRI acquisition parameters of resting state fMRI, DSI and T2-weighted images.

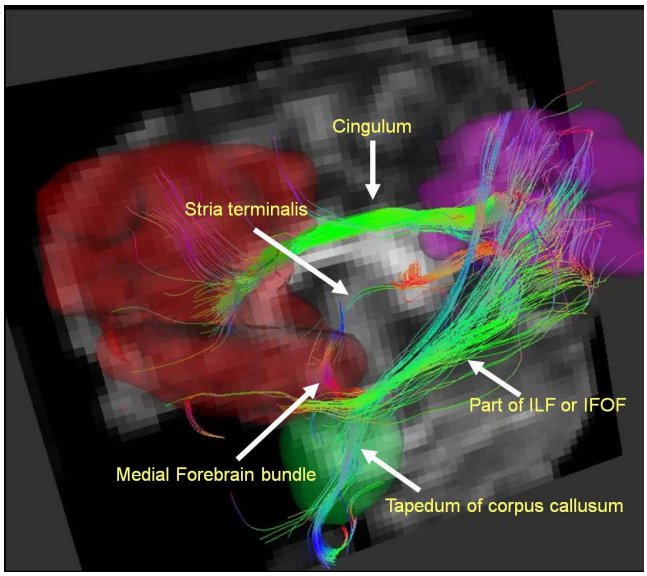

Figure 1. (a) The tractography of the connective fiber tracts in DMN. The red ROI is MPFC, purple one is PCC, and green one is left MTL.

References

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