cephalus can be treated by shunting [7]. Early shunting is key to an almost complete neurological recovery [7,9].

In a patient where multiple shunts are required, as in our case of complex hydrocephalus, it is important to recognize that multiple CSF flow diversion devices in different locations in the ventricular system can lead to low pressure hydrocephalus and paradoxical ventriculomegaly with risk of brain herniation. If there is over shunting in one region causing a pressure gradient between the supratentorial and infratentorial regions, then herniation can occur as seen in our case even in the presence of low intracranial pressure. If multiple shunts are required it is important to recognize that the patient is at risk for developing this type of herniation. Careful attention must be paid to the type of shunt being used in each region of the ventricular system. In cases where multiple shunts are required and there is a potential risk of creating a pressure gradient between compartments, programmable shunts should be placed when possible to avoid unnecessary shunt revisions.

4. Disclosures

The patient and the patient's family consent to the submission of this article for publication in this journal. The authors report no conflict of interest.

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Connection between bilateral temporal regions: Tractography using human connectome data and diffusion spectrum imaging

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ABSTRACT

Temporal lobe epilepsy often propagates inter-hemispherically. Although the pathway of the propagation was verified by electrophysiology, the trajectory remains poorly defined. DTI can depict fiber trajectory but it has limited angular resolution and cannot adequately assess cortical regions. We visualized potential pathways of bitemporal epilepsy propagation using diffusion spectrum imaging (DSI) with data consisting of 8 groups of 514 directions and diffusion templates of 842 subjects from the human connectome project (HCP). We verified the results with reference to the axonal-tracing literature. Both the large population overall and individual connection properties were investigated. In both the HCP 842 atlas and DSI individual data, the bilateral temporal pole was found to connect via the anterior commissure. The splenium of the corpus callosum was divided into 3 subregions (CS1, CS2, CS3) according to the form of connections. CS1 was predominately located at the rostral third and the dorsal part of middle third of the splenium; it communicated with the bilateral parietal lobe. SC2 was predominately located at the ventral middle third of the splenium. Fibers passed through the lateral wall of the lateral ventricle and connected to regions lateral of the occipitotemporal sulci. CS3 was located at the caudal third of the splenium. Together with the hippocampal commissure, its fibers constituted the medial wall of the lateral ventricle and distributed medially to the occipitotemporal sulci. The trajectory of bilateral temporal connections was visualized in this study; the results might help in the understanding and treatment of inter-hemispherical propagation of temporal-lobe epilepsy.

1. Introduction

Temporal lobe epilepsy (TLE) often propagates inter-hemispherically and usually involves the contralateral temporal lobe [1,2]. Significant effort has been expended over decades in exploring the neural connections between the bilateral temporal

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lobes using electrophysiological methods. Consequently, inter-hemispherical connections were found to exist [3,4]. Further, studies of non-human primates have identified a potential pathway through the anterior commissure, splenium of the corpus callosum, and the dorsal hippocampal commissure [5]. However, the trajectory of the pathway in living humans remains unclear. Localizing these connections would facilitate understanding of propagation in TLE patients, and potentially assist in treatment of the disease.

Diffusion tensor imaging (DTI) allows visualization of white matter connections [6]. However, DTI only estimates the average within-voxel diffusion and therefore is unsuitable for assessing cortical connections [2,7]. Additionally, it cannot deal with crossing fibers and produces multiple artifacts [7]. In recent decades, advanced diffusion methods, such as high angular resolution diffusion imaging (HARDI) [8] and diffusion spectrum imaging (DSI) [9] were proposed to solve these problems. Both techniques have high angular resolution and can cope with complex fiber architectures [10]. Currently, to the best of our knowledge, bilateral temporal connections have not been investigated via advanced diffusion techniques.

In this study, group-averaged HARDI data of a large population of 842 subjects from the human connectome project (HCP) and local individual full Q-space DSI data (514 directions) were used, to explore the connections between the bilateral temporal lobes, including fibers crossing the anterior commissure, corpus callosum, and dorsal hippocampal commissure. Previous axonal-tracing studies were then considered to further validate the results. Potential clinical usage of these connection data is discussed.

2. Methods

2.1. Participants

Full q-space DSI data were acquired from eight healthy right-handed participants (6 men, 2 women; average age: 24.43 years, age range: 22.8–27.0 years). The MRI scan was performed from March 1st to May 1st, 2016. The protocol was approved by the ethics committee at PLA General Hospital.

2.2. Data collection and ODF reconstruction

A Siemens Prisma MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with a 64-channel head coil was utilized in this study. Head motion was reduced by using a head stabilizer. A 43-min DSI 2D echo-planar imaging sequence was used with the following parameters: 514 directions, b-values ranging from 275 to 7015 s/mm^2, echo time (TE): 97 ms, repetition time (TR): 5000 ms, voxel size: 2.2 mm × 2.2 mm × 2.2 mm, field of view (FOV): 220 mm, multi-band acceleration factor: 2. Sagittal T1-weighted structural images were obtained using the following parameters: TR: 2110.0 ms, TE: 2.3, voxel size 0.7 mm × 0.7 mm × 0.7 mm. All diffusion data in this study were processed by DSIstudio (http://dsi-studio.labsolver.org/). Generalized q-sampling imaging [11] was used to reconstruct the orientation-distribution function (ODF) map. The diffusion sampling length ratio was 1.1 with ODF sharpening off.

2.3. HCP-842 subjects' diffusion data

The HCP-842 atlas (http://dsi-studio.labsolver.org/download-images/hcp-842-template) was also used in this study. Diffusion MRI data of 842 subjects (372 men, 470 women; ages: 22–25, $n = 176$; 26–30, $n = 367$; 31–35, $n = 293$; >36, $n = 6$) from the human connectome project (2015 Q4, 900-subject release) were averaged into the MNI space using q-space diffeomorphic reconstruction [12]. The spin-distribution function [11] was obtained with a diffusion-sampling length ratio of 1.25; output resolution was 1 mm.

2.4. Fiber tracking and data analysis

Both the DSI individual data and the HCP 842 atlas data were used to perform fiber tracking. The HCP 842 atlas was used to examine large-population properties and the DSI individual data were used to assess individual properties. The quantitative anisotropy (QA) threshold was set at a value such that the diffusion signal could fill the structural image without obvious noise. Other tracking parameters were as follows: angular threshold: 80, step size: 0.4 mm, smoothing: 0.80, minimum length: 5.0 mm, and maximum length: 300 mm. Trilinear interpolation and the streamline algorithm were used. Each tracking process terminated if 10,000 tracts were obtained. The tracts were visualized by preset regions of interest (ROI) and regions of avoidance (ROA) based on the ODF map. Axonal labeled-tracing results of prior studies were used to evaluate the diffusion findings.

3. Results

The anterior commissure, corpus callosum, and dorsal hippocampal commissure were found to be connected with the bilateral temporal lobe in all the individual participants and the HCP averaged data.

3.1. Anterior commissure

In this study, with the ROI shown in Fig. 1C–F, the anterior commissure was visualized both in large population data and individual participants Fig. 1. The anterior branch of the anterior commissure connected with the orbitofrontal cortex, while the posterior branch of the anterior commissure spread from the temporal pole to the occipital lobe and the parietal lobe. Harvest connections could be found between the bilateral temporal poles by further segmentation (Fig. 1C and D). However, no convincing inter-hemispherical connections between other part of the temporal lobe were visualized in this study.

3.2. Splenium and dorsal hippocampal commissure

The splenium of the corpus callosum connects the bilateral temporal lobe in non-human primates [5]. It was further divided into the ventral splenium and dorsal splenium by Demeter et al. [5]. The fibers from the cortical wedge formed by the occipitotemporal and calcarine sulci and from slightly further lateral in the occipital lobe progress to the inferior forceps and travel medially to the lateral ventricle and cross the midline at the ventral splenium. In contrast, the dorsal splenium primarily consists of fibers from the lateral side of the occipitotemporal sulci. The dorsal hippocampal commissure, which attaches to the splenium, predominately communicates with the bilateral parahippocampal gyrus [5].

In this study, to identify the region in the corpus callosum that connected with the temporal lobe, we first performed a whole corpus callosum seeding in the HCP 842 dataset. We found that these commissural fibers were mainly located at the splenium (Fig. 2). The splenium was seeded for a second time by subregions of approximately 1 mm voxel thickness within the single midsagittal plane (Fig. 2B). Fibers passing each single layer were visualized respectively and further parcellation was carried out in the mid-