Deep brain stimulation in Parkinson's disease: The potential benefit of preoperative DTI

National Institute of Neurological Disorders and Stroke

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Poster # 3006

Background

Deep brain stimulation (DBS) is an effective therapy for the treatment of Parkinson's disease (PD).
Clinical effectiveness is achieved by targeting the subthalamic nucleus (STN) or the internal portion of the globus pallidus (1). Stimulation of white matter structures adjacent to those main targets may also provide clinical benefit (2). Mechanisms are currently not well understood, and proper postoperative localization of electrode remains difficult.

Objectives

- To provide a tool for optimal electrode localization
- To characterize neuronal connectivity networks associated with favorable clinical outcomes, and potentially predict the most effective electrode combinations using preoperative DTI.

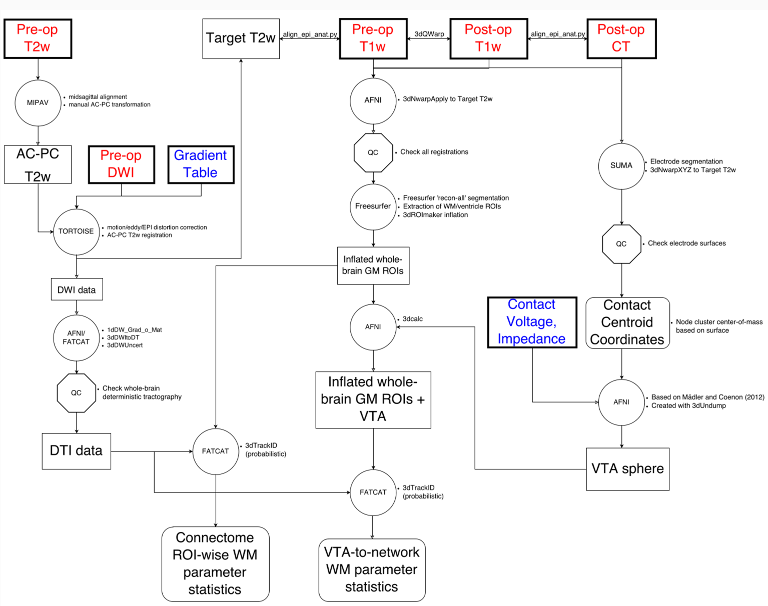
Methods

Subjects: 22 patients (11 female, age 57.4 ± 9.1 years) with idiopathic PD (disease duration 13.3 ± 6.3 years) who received bilateral STN DBS surgery. All patients were implanted with Medtronic 3389 electrodes.

Imaging:
- Pre-op MRI: (3T Philips Achieva XT) T1 turbo-field-echo, T2 turbo-spin echo, high-angle EPI diffusion weighted images (33 directions)
- Post-op MRI: (1.5T Philips Achieva XT) T1 fast-field-echo
- Pre- and post-op CT: Siemens SOMATOM

Pre-processing pipeline
- Pre-op T2: Midsagittal-aligned and ACPC-transformed in MIPAV[3]
- Diffusion MR data: motion-, eddy-, and EPI distortion-corrected and registered to T2 in TORTOISE[3]
- Pre-op T1: Tissue segmentation to regions of interest (ROIs) with FreeSurfer[5]
- All images co-registered using AFNI[6]
- DBS electrodes/contacts reconstructed using SUMA[7]

DTI-FATCAT tractography
- Tensors estimated using non-linear approach with FATCAT[8]
- Fractional anisotropy (FA) and principal direction uncertainty estimated with 500 jackknife-resampling iterations
- Volumes of tissue activation (VTAs) estimated from patient- and contact-specific voltage and impedance values[9]
- VTA-brain connectivity estimated using probabilistic tractography with FATCAT
- VTA-ROI tracts normalized by the total number of tracts from the VTA

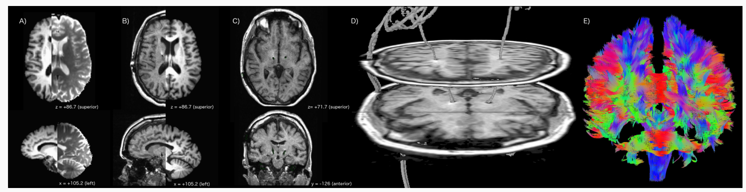


Bold boxes represent input data. Red text represents images in original space, and blue text represents non-imaging input data. Rectangles with black text represent intermediate data in target T2w space, circles indicate software used, and octagons represent quality-check points, and rounded rectangles indicate output data. Specific functions/steps are annotated next to shapes. T1w/T2w=T1-/T2-weighted images, DWI=Diffusion Weighted Images, DTI=Diffusion Tensor Imaging, AC-PC=Anterior/Posterior Commissure-marked, GM=Grey Matter, ROIs=Regions of Interest, VTA=Volume of Tissue Activated, WM=White Matter, QC=Quality Check.

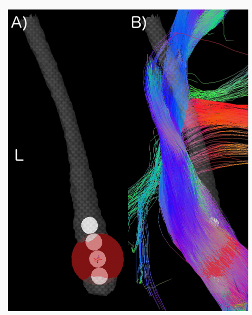
Summary

- We built an open source processing pipeline which will be available within AFNI.
- We characterized specific connectivity patterns of the most clinically beneficial electrodes in a group of 22 PD patients treated with STN DBS by using preoperative probabilistic tractography
- Our findings could serve as a pipeline for the development of preoperative imaging and programming interfaces of STN DBS in PD.

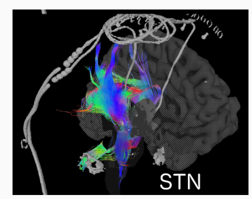
Results



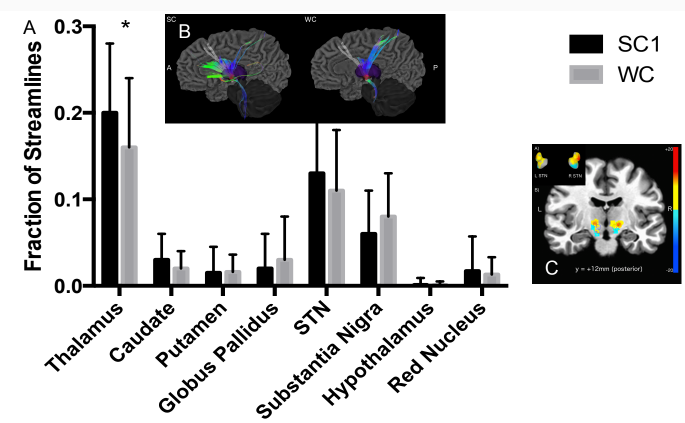
Registration quality
Image and coordinate data shown is from a single subject. A) Pre-operative T1w (left) and target T2w (right) volumes overlaid in the axial (top) and sagittal (bottom) planes. Volumes underwent an affine registration with AFNI's 'align_epi_anat.py'. B) Post- (left) and pre-operative (right) T1w volumes overlaid in the axial (top) and sagittal (bottom) planes. Volumes underwent a nonlinear registration in the AFNI function 'auto_warp.py'. C) Post-operative T1w volume overlaid with green outline of CT surface. Volumes underwent an affine registration with AFNI's 'align_epi_anat.py'. D) Reconstructed 3D surface of postoperative T1w-registered CT volume with 2 axial slices of post-operative T1w volume. E) Anterior view of whole-brain deterministic tractography with properly formatted gradient direction data.



DBS Electrode/Contact Reconstruction/Volume of Tissue Activation estimation
A) The left electrode of a patient, with white spheres (1mm radii) representing reconstructed DBS contacts. Actual contact radius is 0.75mm. The red sphere centered at the second-to-bottom contact represents the estimated volume of tissue activation based on chronic stimulation voltage and electrode impedance. B) The mini-probabilistic tracts passing through this sphere.



SUMA display of DBS Electrode reconstruction and DTI tractography from STN seed



Clinical outcome: A) Bar graphs representing tractographic profiles of stimulating contacts at 1 month post-op (SC1) versus worst contacts (WC) across all the subjects. Contacts chosen for chronic stimulation have a larger interaction with white matter structures (B) associated with the thalamus, compared to contacts less often selected for chronic stimulation. These results suggest that besides STN stimulation, the modulation of white matter tracts that run in close proximity to the dorsal STN (C), which could correspond to the ZI and/or selected pallidothalamic fibers, play an important role in the mechanism of action of DBS.

References

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Acknowledgements: THIS WORK WAS SUPPORTED BY THE NINDS INTRAMURAL PROGRAM
We thank the PD Clinic staff: Beverly McElroy, RN and Mae Brooks.

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