Ventral Intermediate Nucleus (VIM) Localization with Probablistic Diffusion Tractography

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Introduction:

Thalamotomy targeting the thalamic ventral intermediate nucleus (VIM) has long been a treatment for tremor. Clinical Research has proved that thermal ablation of VIM can relieve the symptoms of medically refractory essential tremor[1]. However, identifying VIM for surgical planning is both time consuming and challenging as it does not have unique MR contrast characteristics. The prevailing localization methods rely on atlas-based coordinates to identify VIM and not upon patient specific anatomy[1,2]. Probabilistic diffusion tractography has been used to identify connectivity of different thalamic subdivisions to corresponding cortical regions[3,4]. However direct evidence concerning the connection between VIM and cortex is still sparse and is derived mainly from limited post-mortem observations. The goal of this study is to identify cortical regions that are connected with VIM and to facilitate the localization of VIM to assist surgical planning.

Materials and Methods:

Thirteen healthy volunteers were included in this study with imaging performed on a Siemens Tim-Trio 3T MRI scanner using a 12-channel receive only head coil. Diffusion weighted images were obtained with b = 1000, 2000s/mm^2 at 30 directions, together with 4 b0 images, in-plane resolution = 2.7mm^2, TE/TR = 101ms/6000ms at a slice thickness of 2.7mm with two averages. A high-resolution T1-weighted-MPRAGE (TE = 3.44 ms, TR = 2250ms, TI = 900ms, flip angle = 9º, resolution = 256 × 256 × 96, FOV = 22 cm, sl. Thick = 1.5 mm) image was acquired for anatomic reference. FMRIB's Diffusion Toolbox was used to generate DTI maps and to estimate crossing fibers based on the Bayesian estimation of the probability distribution of the tensor orientation within each voxel[3,4]. The VIM location was identified by a radiologist on a high-resolution T1 image in the MNI space based on the atlas-based VIM coordinates. To account for small individual anatomical variability, the gold standard VIM mask (VIM_{gold}) was taken as a 544 mm^3 volume centered at the identified VIM location. Probabilistic tractography was carried out from VIM_{gold} for every subject and the common cortical locations that had projected tracts from VIM_{gold} from all subjects were identified. These cortical regions were further subdivided to smaller sections based on the IIT-GM-Destrieux-atlas-256 from NITRC and used as seeds for probabilistic tractography back to the thalamus to pin point the common cortical region that uniquely projects to the VIM (Cor_{VIM}). The tractography identified VIM area (VIM_{tract}) in each individual's DTI space and was verified against VIM_{gold} that was warped to each individual space. Dice index[5] was used to determine the extent of volumetric overlap between VIM_{gold} and VIM_{tract}., the radiologist identified atlas based VIM region vs the identification of VIM from the proposed algorithm respectively

Results:

Fig.1 shows the whole brain connectivity maps from the VIM for a representative subject. In the zoomed view of the green box, the blue areas indicate the white matter tract region identified to be common to all subjects that provided reliable fiber projection back to the VIM_{gold} mask in the thalamus (named as Cor_{VIM}). Cor_{VIM} is centered at (70, 55, 50) mm in MNI space, which is located at the intersection of the primary motor and somatosensory cortex. We then manually identified this Cor_{VIM} in coronal FA maps of each subject as the seed region for VIM tracking. Fig.2 shows the connectivity maps from Cor_{VIM} to the thalamus in eight example subjects, indicating a good correspondence of VIM_{tract} and VIM_{gold}. The resulting dice index[5] is 67.3±13.47% for all subjects.

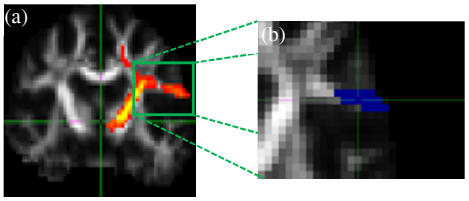

Fig.1: Connectivity maps originated from VIM (a). In (b), the blue region pinpoints the common region which provides a fiber projection back to VIM.

Discussions:

In this study, we provide preliminary evidence that probabilistic tractography can be used to identify the VIM using information from cortical regions that are more likely to be connected with the VIM. When compared to IIT-GM-Destrieux-atlas-256, Cor_{VIM} corresponds to the area around primary motor cortex, supramarginal gyrus, and primary somatosensory cortex, which may explain why VIM ablation helps to alleviate symptoms of essential tremor. On the other hand, because atlas based identification does not take into account several factors including, age, brain atrophy etc, identification of VIM based on connectivity to these cortical regions may improve the work-flow of the surgical procedures (DBS & Focused ultrasound) and minimize side effects associated with thalamotomy that can arise from imprecise VIM targeting, including speech and sensory disturbances. Our preliminary results hold promise for the identification of VIM based on individual patient anatomy but require validation in a larger cohort of individuals.

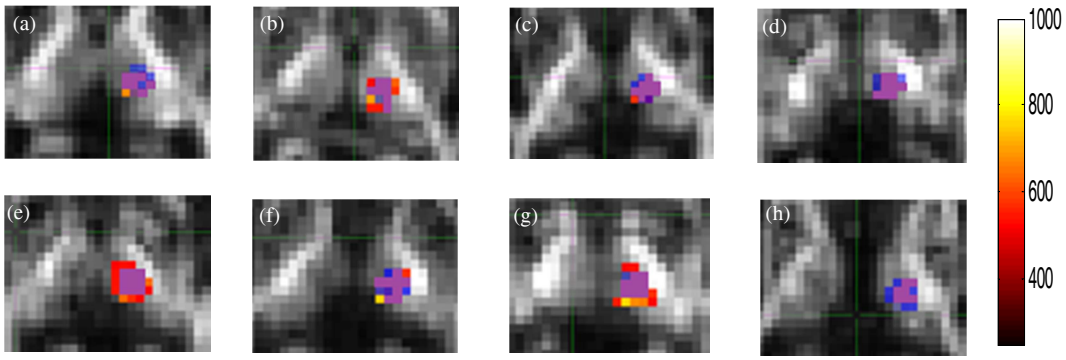

Fig.2: (a)-(h) are the probabilistic tractography map from Cor_{VIM} in eight representative volunteers. VIM_{tract} is shown in hot-colored bar, and VIM_{gold} is in blue. The purple region is the overlapping of VIM_{tract} and VIM_{gold}.

References

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