A VASCULAR SAFETY INDEX FOR STEROTACTIC TARGETING OF DEEP BRAIN STRUCTURES

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Background

Stereotactic implantation of acute, chronic or semi-chronic depth electrodes in Deep Brain Stimulation (DBS) and Stereoencephalography (SEEG) is required for electrophysiological mapping of the areas of interest and for applying therapeutic electrical stimulation.

One major problem common to DBS and SEEG is the stereotactic placement of electrodes in deep brain structures while avoiding major blood vessels present along the electrode paths.

DBS targets deep structures primarily for the treatment of movement disorders, but several new applications are emerging. The procedure requires the insertion of up to 5 acute microelectrodes per target for functional mapping, followed by the placement of unilateral or bilateral chronic stimulation electrodes.

SEEG is the only technique that provides direct access to electrophysiological recordings in the depth of the seizure onset zones, for pre-surgical evaluation of patients with refractory epilepsy. Long-term EEG recordings are made using a significant number of multi-contact depth electrodes, typically ranging from 8 to 15 electrodes, each having 8 to 18 contacts.

Objectives

The general aim is simplifying and improving the stereotactic planning for minimal interference with the brain's vascular network during the implantation of depth electrodes. Our goal is to make the implantation procedures safer and faster.

A first specific aim is to introduce an objective measure reflecting the proximity of the blood vessels for each trajectory. Therefore, we define a trajectory safety index (SI), based on a maximum intensity projection (MIP) algorithm along the trajectory path.

Second, we would like to establish an automated algorithm for suggesting alternate trajectories presenting a higher vascular safety.

Methods

A 3D model of the vasculature was obtained by filtering the contrast-enhanced MRI's using a 3D Frangi vesselness filter (Frangi et al, 1998). The processing was performed in Matlab (Mathworks, Natick, MA). The filtered volume was visually inspected (fig 1) by creating a 3D isosurface, then exported as DICOM series.

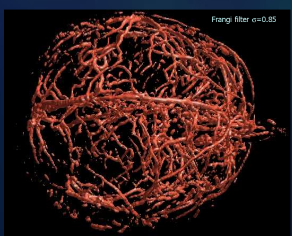

Figure 1. 3D reconstruction of brain's blood vessels obtained by applying a 3D Frangi filter on a contrast-enchanced MRI

The Frangi-filtered DICOM series were used along with the other scans (CT, MRI) in the surgical planning software (Waypoint Navigator, FHC Inc, ME) to plan trajectories for DBS and SEEG procedures (fig 2). The planning software's built-in 3D isosurface representation was used for the initial trajectory planning avoiding blood vessels.

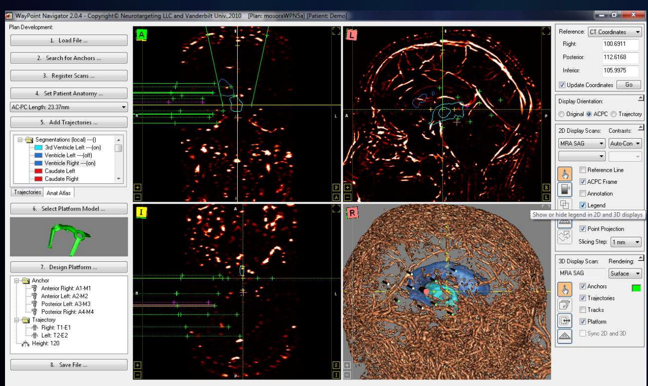

Figure 2. Screenshot of the Waypoint Navigator planning software showing the planned trajectories overlaid with the Frangi-filtered images. The 3D reconstruction of the vasculature is shown in the bottom-right panel.

To objectively describe the vascular safety of each electrode trajectory, a Safety Index (SI) was defined as the distance to 1 of the maximum intensity value along the trajectory intersecting the normalized and smoothed 3D volume of the blood vessels (fig. 3):

$$\boldsymbol{SI} = 1 - \max(\boldsymbol{I}(\boldsymbol{x}))$$

Where $I(x)$ is the intensity curve obtained by 3D linear interpolation of the filtered volume.

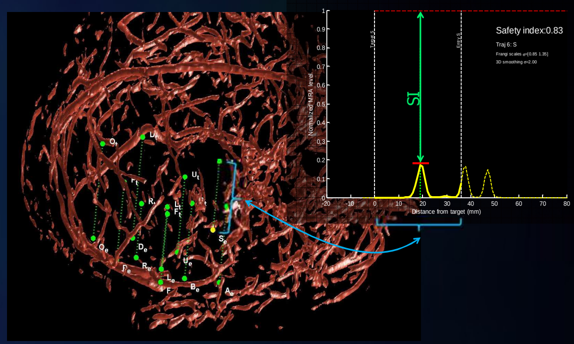

Figure 3. Safety index for supra-Sylvian electrode "S" in an SEEG implantation.

For the algorithm to better detect the proximity of the blood vessels, an effective enlargement of the blood vessels was achieved by smoothing of the thresholded and normalized volume using a 3D gaussian kernel having $\sigma=2^3$ voxels.The smoothed volume was re-thresholded at one tenth of the original value.

Alternate trajectories were suggested by calculating the trajectory safety index for a grid of entry points surrounding the initial one (fig 4).

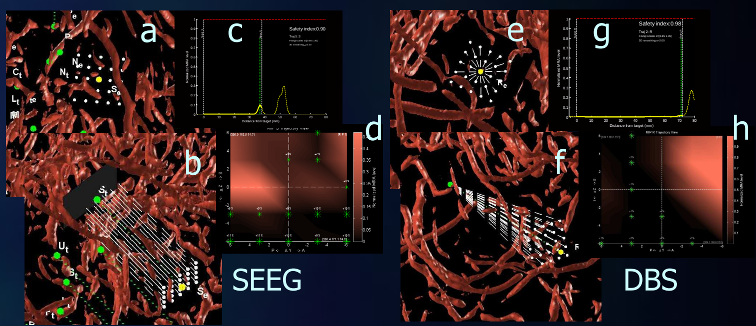

Figure 4. The grid of alternate trajectories tested for higher SI in orthogonal (a) and side (b) views, for SEEG; c) the safety index for the center trajectory; d) the MIP map for the alternate trajectories, those having a higher SI marked at their corresponding location; e-h) same as a-d, but using a polar geometry, used for mostly for DBS procedures and when using Leksell frame.

Depending on the procedure and the type of stereotactic frame used (Leksell or mT Platform), maximum intensity projection (MIP) on the smoothed volume was calculated on parallel (mT Platform) or polar (Leksell) alternate tracks. Alternate trajectories having a lower MIP and correspondingly a higher safety index were suggested.

The implantation was performed using Leksell or mT Platform stereotactic device, customized for each patient (fig. 5).

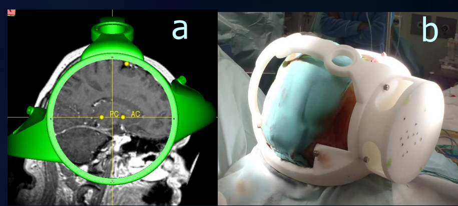

Figure 5. a) mT Platform model generated by the planning software, centered on the MCP point; b) the platform and grid used for the orthogonal implantation of SEEG electrodes, attached to patient's head.

Results

We have applied the calculation of the safety index to the targeting of subthalamic nucleus (STN) for deep brain stimulation (DBS) of Parkinsonian patients and to the implantation of depth electrodes for stereoencephalographic (SEEG) monitoring of epileptical patients. A retrospective analysis on n=20 STN targets, resulted in a SI = 0.94±0.11 (mean±sd). The method was prospectively used for n=28 SEEG electrodes implantation having SI = 0.95±0.08, suggesting alternate trajectories having a higher safety index.

Conclusions

The trajectory safety index we have defined may represent a useful tool for minimizing risks of brain haemorrhage when targeting deep brain structures. The algorithm suggesting alternate trajectories with higher safety index helps in reducing the planning duration.

Acknowledgments

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References

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