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Use of efficacy probability maps for the post-operative programming of deep brain stimulation in essential tremor

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ABSTRACT

Introduction: Post-operative programming of deep brain stimulation for movement disorders can be both time consuming and difficult, which can delay the optimal symptom control for the patient. Probabilistic maps of stimulation response could improve programming efficiency and optimization.
Methods: The clinically selected contacts of patients who had undergone ventral intermediate nucleus deep brain stimulation for the treatment of essential tremor at our institution were compared against contacts selected based on a probability map of symptom reduction built by populating data from a number of patients using non-rigid image registration. A subgroup of patients whose clinical contacts did not match the map-based selections prospectively underwent a tremor rating scale evaluation to compare the symptom relief achieved by the two options. Both the patient and video reviewer were blinded to the selection.
Results: 54% of the map-based and clinical contacts were an exact match retrospectively and were within one contact 83% of the time. In 5 of the 8 mismatched leads that were evaluated prospectively in a double blind fashion, the map-based contact showed equivalent or better tremor improvement than the clinically active contact.
Conclusions: This study suggests that probability maps of stimulation responses can assist in selecting the clinically optimal contact and increase the efficiency of programming.

1. Introduction

Essential Tremor (ET) is a common movement disorder affecting between 2–14% of those over age sixty [1]. ET leads to significant morbidity and can significantly affect quality of life [2]. Medications can effectively manage mild tremor, but with disease progression medications lose their effectiveness and lead to intolerable side effects. Deep Brain Stimulation (DBS) of the VIM nucleus of the thalamus was approved by the FDA in 1997. It has been shown to improve tremor by over 83% and improve quality of life up to 12 years after implantation [3–5].

There have been several traditional methods described for the programming of DBS for ET [6–8]. These methods involve evaluating each of the four contacts for the threshold for both side effects and efficacy, adjusting the various parameters in a consistent pattern. This is generally done about one month post-lead implantation, which allows sufficient time for resolution of edema and the lesional effect of surgery to subside. Programming can be a time consuming process and may have to be done with little objective clinic information if there is a profound lesioning effect and hence little return of tremor [7]. Patients may then be required to return to clinic for additional extraneous programming sessions leading to a delay in tremor control and incurring additional costs in time and travel. Currently the commercially available lead has four active contacts. With the future direction of lead technology potentially involving eight plus contacts and directionally segmented leads, it will be impossible to reasonably evaluate all of the possible combinations [8]. A system needs to be developed to allow for more efficient programming.

In Parkinson's disease (PD) with Subthalamic Nucleus (STN) DBS it has been shown that with information about the location and proximity of the lead to other neuronal elements, programming response can be improved, both in terms of motor response and side effect reduction using computational models of volumes of tissue activation [9–11]. Such models have been created with respect to the anatomy for programming assistance [12,13]. A

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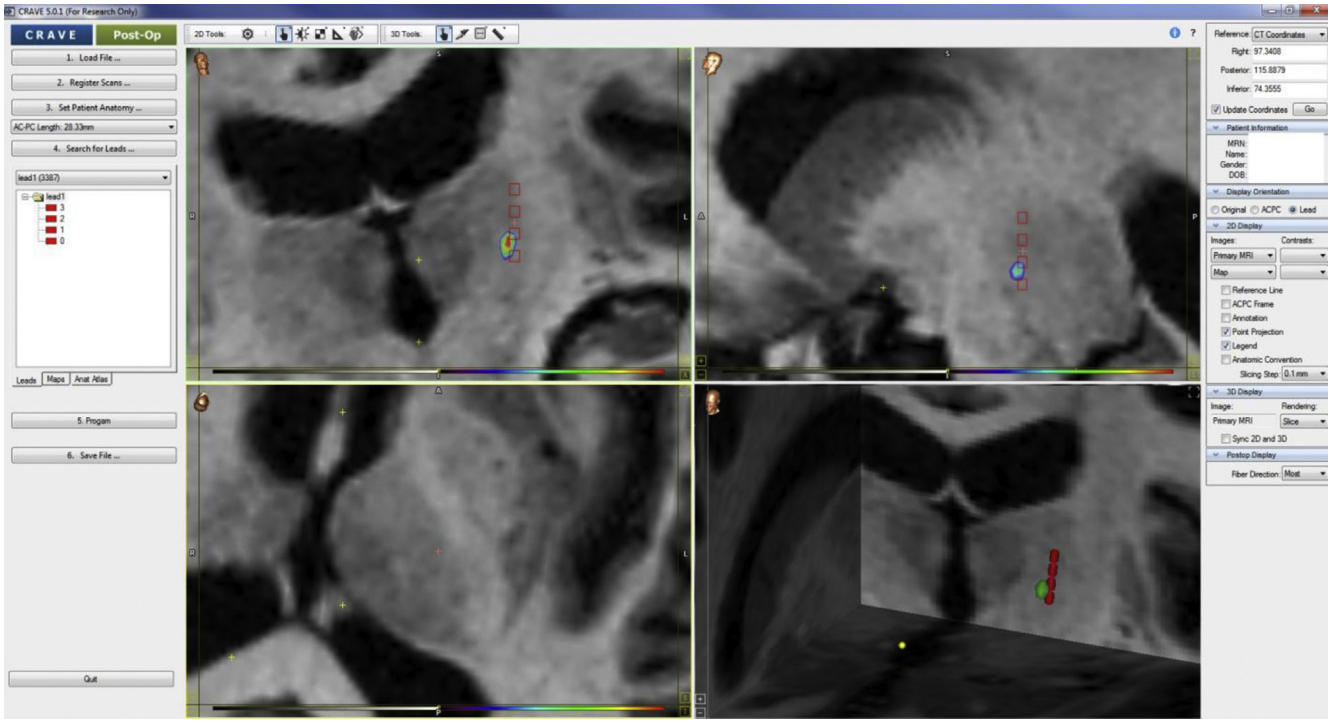

Fig. 1. CRAVE software interface that shows probabilistic efficacy map for an ET Vim-DBS patient and extraction of the DBS electrode implanted in that patient overlaid on the patient's MRI. A 3D rendering is also shown.

Table 1
Lead configurations in the study and the distribution of retrospective matches between the map-based and clinically active contacts.

Lead configuration	Number of leads	Leads where map and clinic contacts were an exact match	% Exact match	Leads where map and clinic contact were off by one contact	% Off by at most one contact
Monopolar	25	11	44	9	80
Double monopolar	8	6	75	1	88
Triple monopolar	1	1	100	–	–
Monopolar interleaving	1	1	100	–	–
Totals	35	19	54	10	83

limitation of using the anatomy to guide programming is that there is a lack of consensus on the ideal anatomical location for symptom reduction response to stimulation [14]. For example, both the dorsal part of the STN and zona incerta (ZI) are known to produce symptom relief in PD [15]. Basing programming decisions on functional outcome rather than anatomy may allow for more efficient and effective programming. Several functional atlases have been developed using intra- and post-operatively acquired electrophysiological data [16–23]. We recently demonstrated consistency with optimal contact selection by multiple neurologists using an in-house developed software tool for post-operative programming visualization. The functional maps were visualized along with the implanted electrode, the patient's anatomy and models of tissue activation [24]. Here we present the utility of our probabilistic maps in assisting with DBS post-operative programming. We performed both a retrospective study and a small double blind prospective assessment. ET was chosen due to the quicker and more discretely observable response to stimulation in terms of symptom relief.

2. Data and method

With IRB approval and after a signed consent form was obtained, the study was carried out in 20 essential tremor patients who had V-DBS implants at Vanderbilt Medical Center. There were a total of 35 leads evaluated; 15 were bilateral implants and 5 were unilateral. The inclusion criterion was that the patients had to be implanted between one and three years prior to the study. This allowed at least one year for the programming neurologist (years of programming experience varied from 3 years to 15) and the patient to have sufficient time to arrive at a stable electrode configuration and stimulation parameter settings most therapeutic to the patient.

Pre-operative MRI and CT images of the brain were acquired for each patient. A post-operative CT, which we refer to as stable CT (CT-PS), was acquired at least 3 weeks after surgery. Typical CT images were acquired at kVp = 120 V, exposure = 350 mAs and 512 × 512 pixels. In-plane resolution and slice thickness were respectively 0.5 mm and 0.75 mm. MRI images (TR 12.2 ms, TE 2.4 ms, 256 × 256 × 170 voxels, with typical voxel resolution of 1 × 1 × 1 mm^3) were acquired using the SENSE parallel imaging technique (T1W/3D/TFE) on a Philips 3T scanner.

At Vanderbilt, DBS surgeries are performed using a miniature stereotactic frame, the microTargeting platform® (FHC, Inc., Bowdoin, ME). The planned target was typically aimed for the ventro-lateral aspect of the thalamus not far from where the Vim is expected to be located. This allowed the surgical team to explore a wide region around this area using trajectories anterior, posterior, lateral and medial to the planned trajectory. Typical planned target coordinates were 14 mm lateral, 6 mm posterior, and 0.5 mm superior to the mid-commissural plane, but these were tailored to the individual patient during planning based on the patient's anatomy. During surgery, prior to assessing the stimulation response, micro-electrode recordings were done in 3–4 tracks parallel to the planned trajectory. Electrical semi-micro stimulation was then applied every 2–3 mm along these 3–4 tracks resulting in 12–16 stimulation response data points around the planned target. The optimal location for the placement of the final implant was based on a combination of the micro-electrode and stimulation response data. Stereotactic coordinates of the intra-operative stimulation response data were converted to X, Y, Z coordinates in the patient's CT image space (as the platform is built in the CT space) and then mapped onto the MRI space using rigid registration. In order to build probability maps for the