A method for electric field simulations and acceleration measurements for intraoperative test stimulation

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A METHOD FOR ELECTRIC FIELD SIMULATIONS AND ACCELERATION MEASUREMENT FOR INTRAOPERATIVE TEST SIMULATION IN DBS

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Background

Despite an increasing use of deep brain stimulation (DBS) the fundamental mechanisms underlying therapeutic and adverse effects as well as the optimal stimulation site remain largely unknown. So far no group has considered simulations of electric entities for intraoperatively obtained test stimulation data to identify the stimulated volume around intraoperative DBS electrodes. The aim of the present paper is to introduce a method allowing patient-specific electric field simulations for stimulation amplitudes at different anatomical positions and taking into account the obtained clinical results objectively evaluated by acceleration measurements [1].

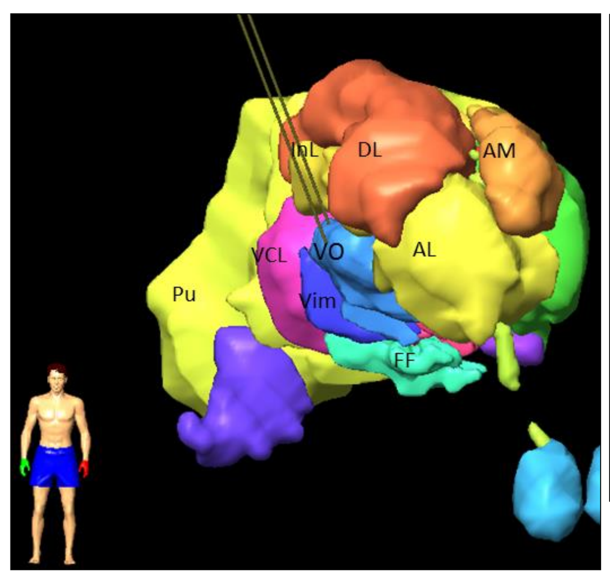
Methods

PATIENTS

- 2 patients with Essential tremor (ET)
- bilateral implantation of DBS electrodes in the VIM (University Hospital in Clermont-Ferrand, France (Clinical study 2011-A00774-37 / AU905))

SURGICAL PROTOCOL

- Preoperative anatomical planning: manual outlining of **VIM** and its anatomic neighbors (Fig. 1) using iPlan (Brainlab, Feldkirchen, Germany) and choice of target and trajectory
- Intraoperative microelectrode recording (MER) and test stimulations
  - in 22 (patient 1) and 28 positions (patient 2) (4 traj. per patient)
  - clinically evaluated using 3-axis accelerometer [Shah, 2013]



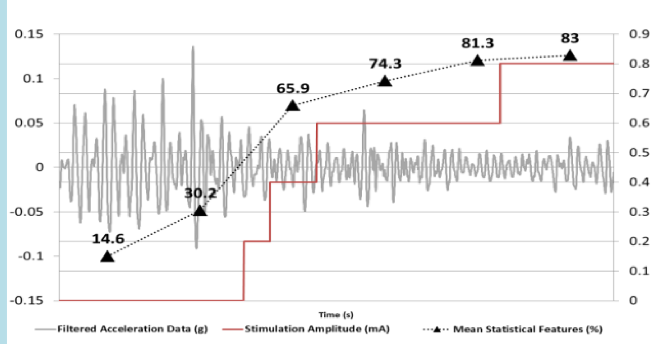
1: ventro-intermediate nucleus (**VIM**)
2: nucleus ventro-oral (**VO**)
3: nucleus intermediate lateral (**InL**)
4: nucleus ventro-caudal-lateral (**VCL**)
5: nucleus dorsolateral (**DL**)
6: pulvinar (**PU**)
7: nucleus anterolateral (**AL**)
8: prelemnsical radiations or prerubral field of Forel (**FF**)
9: nucleus center median (**LaCM**)
10: nucleus ventrocaudal medial (**VCM**)

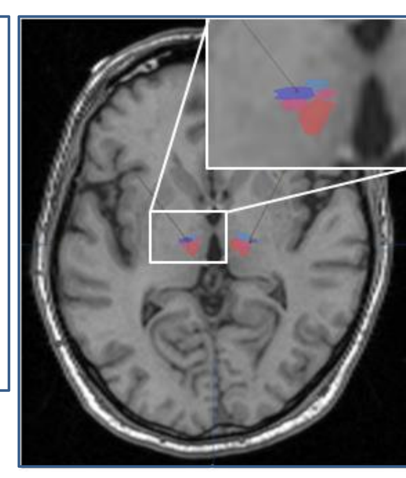
Figure 1: 3D view of the manually outlinig of structures in iPlan (Brainlab). Right side: abbreviation of the structures' name.

DATA ANALYSIS

Acceleration measurements

- Extraction of the statistical parameters
- Determination of the objective clinical improvement [%] for each stimulation amplitude
- Choice of the stimulation amplitudes for simulations



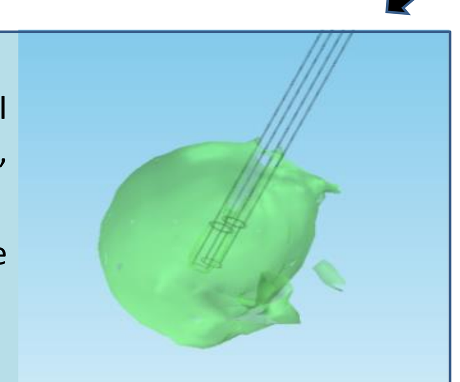


T1 MRI dataset

- Manually outlining of the structures and the target point
- VCM, VIM, VO and LaCM

E-field simulation

- Input: patient specific T1 MRI dataset, target coordinates, stimulation position and amplitude
- Output: Electrical-field isosurface for 0.2V/mm [Åström, 2009]



Structures and trajectories

- Export anatomical structures and trajectory in the CT dataset reference system(VVLink (Brainlab) and VTK (Kitware Inc.)

Combined data analysis

- Analysis per position:

Determination of structures included in the stimulated volume and of the percentage of structure's volume covered

- Analysis per patient group:

Comparison of structure volume covered by isoelectrical field for all stimulation positions and amplitudes of both ET patients

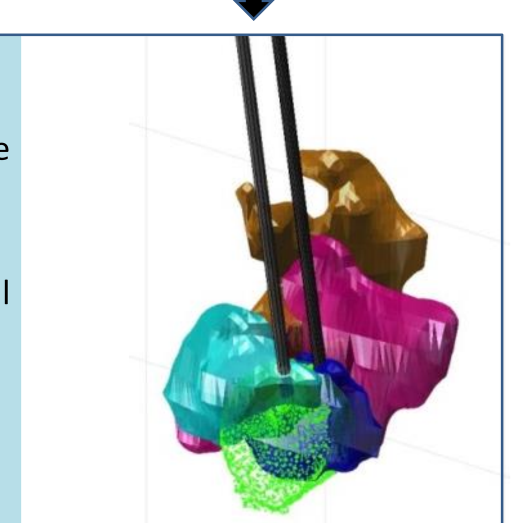


Figure 2: Workflow for generation of patient-specific electric field simulations on patient specific anatomy

Results

- 115 electric field simulations performed for the eight trajectories
- Data can be visualized in 3D and together with the anatomical images (Fig. 3)
- E-field maps show that not always best intraoperative clinical results can be observed in the **VIM** but in the surrounding regions (Fig. 4)
- The visual representation for all performed simulations (Fig.4) of the structures and structure combinations touched by the isoeletrical field and in relation to the corresponding clinical improvement shows:
  - → **VO** and **VCM** often appear together with the VIM
  - → In several cases, **FF** or **PLR** are touched by the isoelectrical field when the improvement is higher
  - → **LaCM** and **VCL** especially appear for lower improvements

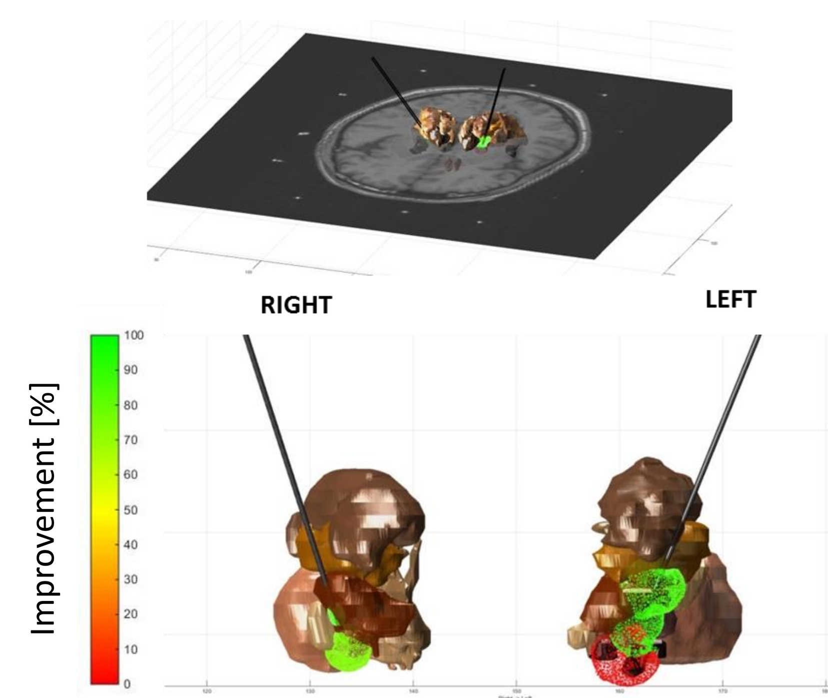


Figure 3: : Isofieldlines simulated for patient 2 for three positions on each central electrode track, color coded following the induced clinical change (green: high improvement; red: low or no improvement) and superimposed to the anatomical structures (brownish color). a) MRI T1 axial image superimposed to 3D structures and isoelectrical fields. b) 3D frontal view of structures and isoelectrical fields.

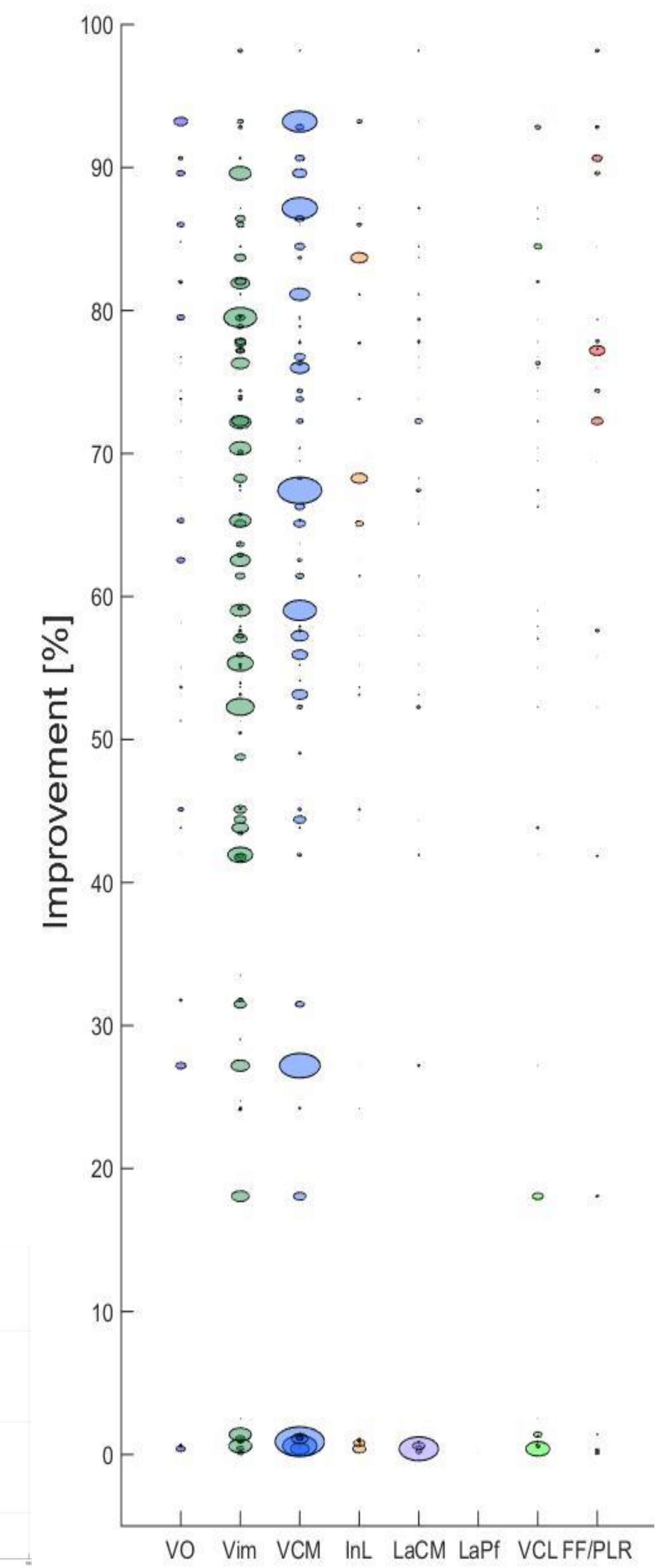


Figure 4: Comparison of the structure appearance (x-axis) in function of the obtained clinical improvement (y-axis) including all performed simulations. Structures appearing in the same simulation have the same improvement value (=same horizontal level). The radius of the circles is proportional to the volume of the structures inside the isoelectrical field [%].

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Discussion

- Workflow and methodology for electrical field simulations on manually outlined anatomical structures have been designed and successfully applied to two patients.
- First results seem to confirm published data hypothesizing that the stimulation of other structures than the **VIM** might at least partially be responsible for good clinical effects: Vassal et al. [Vassal, 2012] already suggested that parts of the ventro-oral nucleus (**VO**) could be appropriate targets as well.
- New concept including a detailed analysis of the isofield maps will allow the **analysis of a high amount of intraoperative data** which might help to elucidate the mechanism of action of DBS.
- **New successful methodology for the interpretation of multiple patients' intraoperative data in relation to the anatomical structures and the objective clinical improvements**.

References

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