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

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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. Computer simulations of electric entities such as electric field or current density are more and more used to try to identify the stimulated volume around implanted DBS electrodes. So far simulations for intraoperatively obtained test stimulation data have not been considered. The aim of the present work was to propose a methodology allowing an optimal exploitation of test stimulation data including a quantitative assessment of the clinical outcome by acceleration measurements. Patient-specific electric field simulations for stimulation amplitudes at different anatomical positions might provide supplementary data about implicated structures and the mechanism of action. In order to illustrate technical and clinical feasibility, the presented methodology has been applied to two patients.

Methods

PATIENTS

- 2 patients with Essential tremor (ET) participating in clinical study
- bilateral implantation of DBS electrodes in the ventro-intermediate nucleus (VIM)

SURGICAL PROTOCOL

- Preoperative manual outlining of VIM and its anatomic neighbors using iPlan (Brainlab, Feldkirchen, Germany) and choice of target
- Intraoperative microelectrode recording (MER) and test stimulations
  - in 24 (patient 1) and 30 positions (patient 2) (4 traj. per patient)
  - clinically evaluated using 3-axis accelerometer [Shah, 2013]

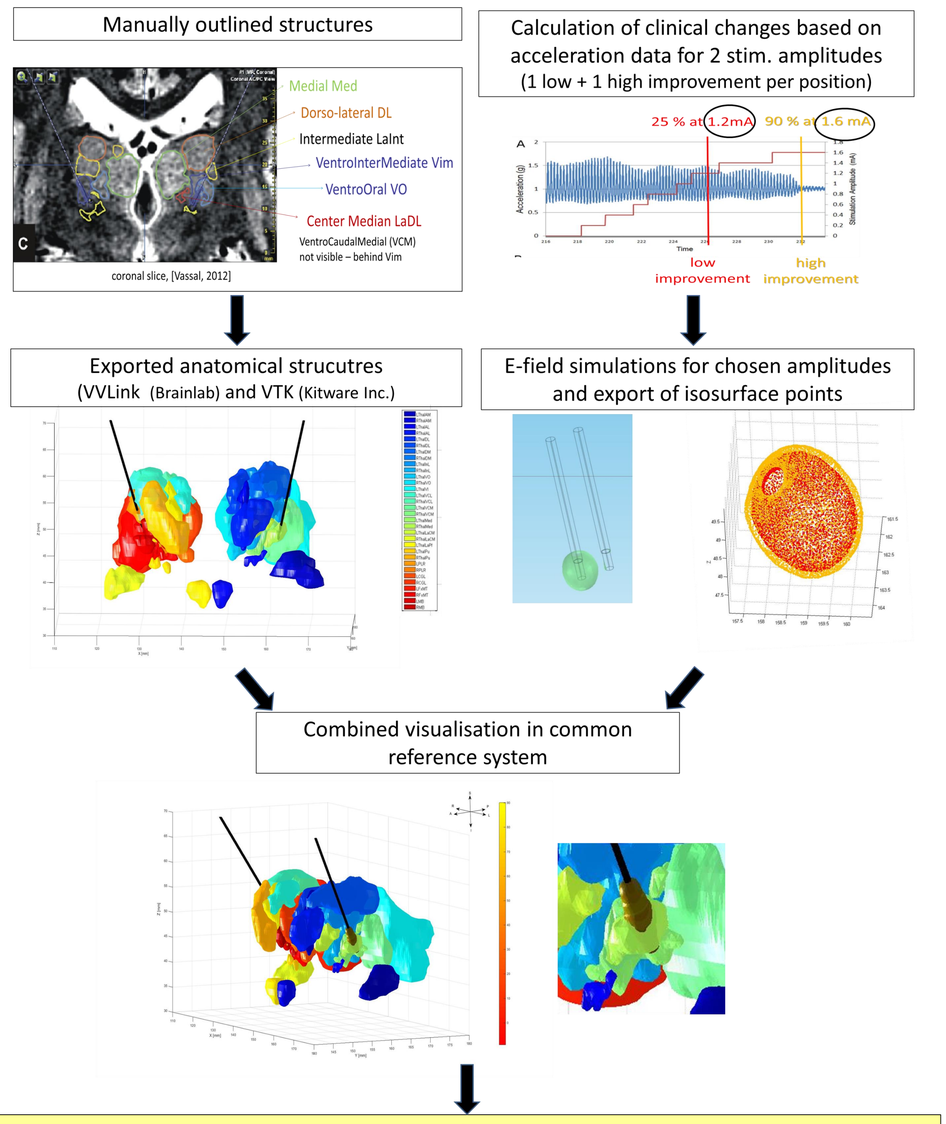
E-FIELD SIMULATION

Input: T1 MRI dataset, stereotactic CT, target coordinates, stimulation position and amplitude

Electric field simulations: Patient specific modeling based on MRI

Output: Electric field isosurface for 0.2V/mm [Dicsfalusy, 2013]

DATA ANALYSIS



Analysis per position Determination of structures included in the stimulated volume and of the percentage of structure covered

Analysis per patient Generation of isofield maps indicating the clinical improvement at several stimulation positions (in overlapping regions => lowest improvement was retained)

Analysis per patient group

- Comparison of structures included in stimulated volume (*simulation-based approach*) and present at the anatomical position of centre of stimulating contact (*classical approach*)
- Correlation analysis between clinical change and structures present in stimulated volume: Calculation of mean ± std

Figure 1: *Workflow for generation of patient-specific electric field simulations on patient specific anatomy*

Results

- 108 electric field simulations performed for the eight trajectories
- Simulation-based versus classical approach (Fig. 2): VO and VCM appear more often; DL appears only with the simulation based approach.
- Low versus high improvement (Fig. 2): Differences in appearance especially in VO, VIM and VCM

Approach	InL		DL		VO		VIM		VCM		LaCM		VCL	
	Low impr.	High impr.	Low impr.	High impr.	Low impr.	High impr.	Low impr.	High impr.	Low impr.	High impr.	Low impr.	High impr.	Low impr.	High impr.
Simulation-based	9	13	8	11	10	16	9	20	10	21	3	5	1	4
Classic	7		0		10		17		7		3		2	

Figure 2: *Differences in the number of appearance between simulation-based and classical approach and between low and high improvement for the simulation based approach*

- Highest improvement at positions were the following structures where present in stimulated volume: **VO (69 ± 21%), VCM (67 ± 24%), VIM (50 ± 19%)**
- E-field maps show as well that not always best intraoperative clinical results can be observed in the Vim but in the surrounding regions (Fig. 3)

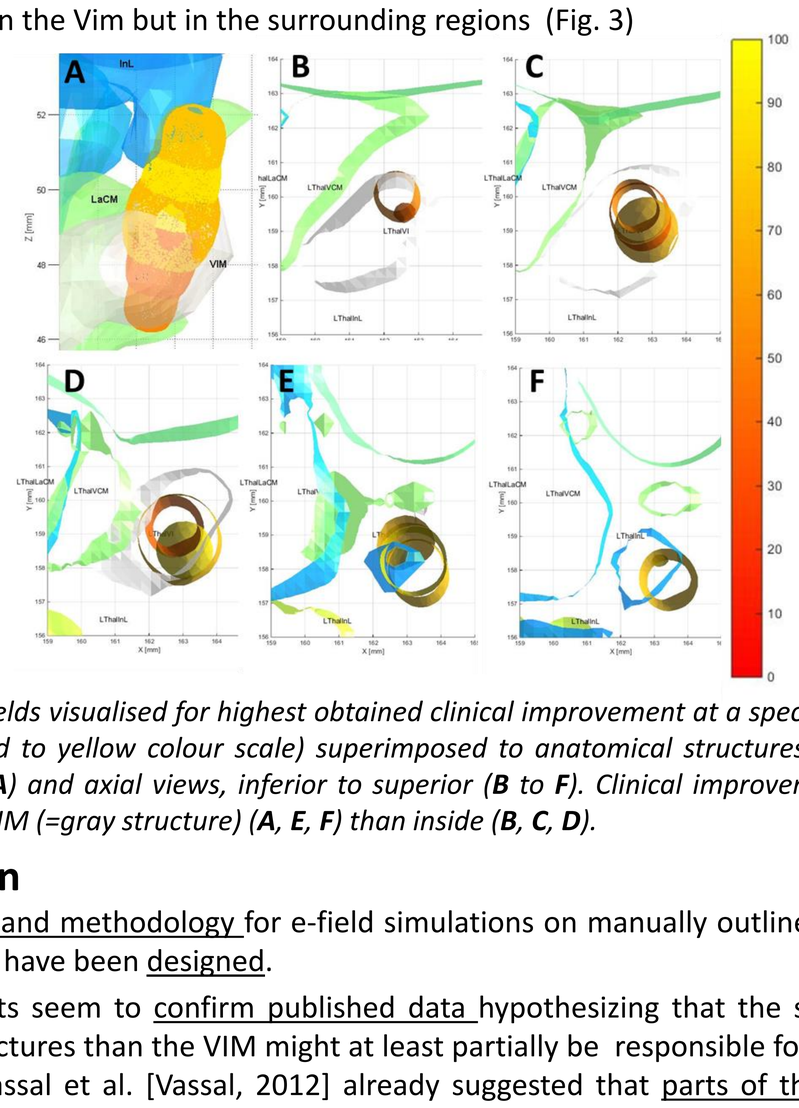


Figure 3: *E-fields visualised for highest obtained clinical improvement at a specific position in patient 1 (red to yellow colour scale) superimposed to anatomical structures: sagital view (right side) (**A**) and axial views, inferior to superior (**B** to **F**). Clinical improvement is higher outside the VIM (=gray structure) (**A**, **E**, **F**) than inside (**B**, **C**, **D**).*

Discussion

- Workflow and methodology for e-field simulations on manually outlined anatomical structures have been designed.
- 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.
- Simulation-based approach clearly brings in supplementary information compared to the classical one. But the analysis of more data is necessary to draw any final conclusion.

References

[Dicsfalusy, 2013] Dicsfalusy, E., et al. Deep brain stimulation - Electric field as a predictor of activation for various neuronal elements. IEEE EMBS Conference on Neural Engineering. San Diego, USA.

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[Vassal, 2012] Vassal F. et al. Direct stereotactic targeting of the ventrointermediate nucleus of the thalamus based on anatomic 1.5-T MRI mapping with a white matter attenuated inversion recovery (WAIR) sequence. Brain Stimul. 5(4):625-33.

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