Computational Modeling of Deep Brain Stimulation in the Globus Pallidus Internus

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Introduction

Background: Dystonia is a neurological movement disorder characterized by sustained muscle contractions that cause twisting and repetitive movements or abnormal postures. Deep brain stimulation (DBS) of the globus pallidus internus (GPi) has been successful in alleviating symptoms for patients who do not respond to medication.

Objective: To determine the volume of tissue activated (VTA) within the GPi and the cortical spinal tract (CST) (side-effect pathway) for a subject treated with DBS for dystonia through computational modeling.

Methods: A general model of GPi DBS, based off of a human brain atlas, was established by integrating several computational modeling programs to ultimately determine the VTA. The DBS lead electrode configuration was altered to assess how changes affect GPi modulation and CST activation.

Results: GPi DBS simulations yielded a combination of cell activation and inhibition. Activation was found to be greatest around the cathode of the DBS lead. Modulated cells were localized relative to the lead and the degree of modulation decreased farther away.

Conclusion: Treatment outcome is strongly dependent on the precise placement of the electrodes in the brain and subsequent adjustment of the stimulation settings to fine-tune the therapy. Patient-specific stimulation settings are required in order to provide maximum GPi modulation with minimal side-effects. This modeling approach can provide a framework for neurosurgeons and neurologists to improve current techniques that will optimize treatment outcome.

Modeling Approach

Rhinoceros
- Trace GPi and CST subnuclei, align traces in space, and render three-dimensional lofts

MATLAB
- Populate subnuclei volumes with neuron models

COMSOL Multiphysics
- FEM to determine electric field around DBS lead

NEURON
- Determine activation voltage of neurons

Results

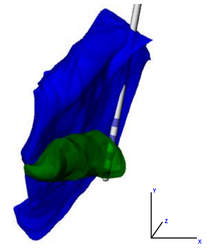

Fig. 1. Front view of the Rhinoceros three-dimensional brain atlas of GPi (green) and CST (blue) subnuclei.

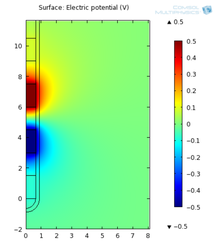

Fig. 2. COMSOL FEM of the electrode-tissue interface.

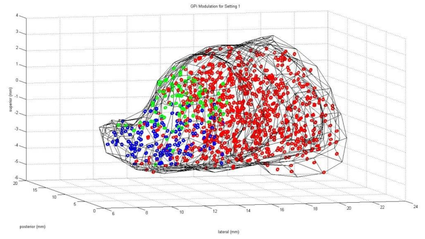

Fig. 3. Three-dimensional plot of GPi modulation for 1000 cells. 'Modulated' cells (activation threshold > 80 Hz) are red, 'inhibited' cells (activation threshold < 20 Hz) are blue, and 'unaffected' cells are green. The stimulation voltage applied was 5.5V.

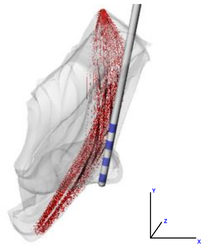

Fig. 4. Rhinoceros model of the activated CST fiber tracts (red) plotted within CST (white). Threshold voltage was set at 5V for each setting.

Table 1
GPi Modulation

	# Cells Modulated	# Cells Inhibited	# Cells Unaffected	% Cells Changed
Setting 1	773	138	89	91.1
Setting 2	195	23	782	21.8
Setting 3	310	18	672	32.8

Table 2
CST Activation

	# Cells Activated	% Cells Activated
Setting 1	154	15.4
Setting 2	165	16.5
Setting 3	105	10.5

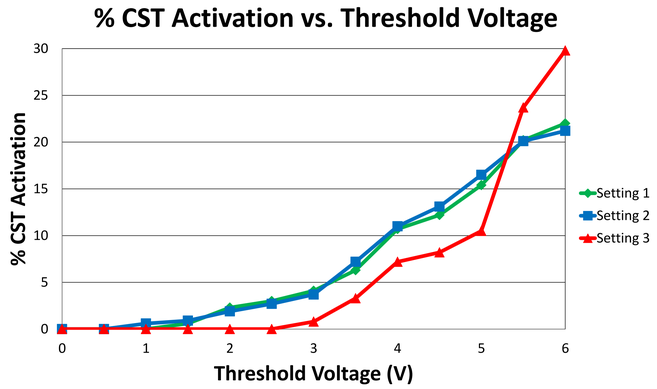

Fig. 5. % CST activation over a range of threshold voltages (0-6V) for each DBS lead setting.

Future Work

- Determine how sensitive DBS lead placement is to the ratio of GPi modulation vs. CST activation
- Evaluate new lead designs (e.g., segmented, directional) and alternative lead trajectories and orientations through the use of three-dimensional FEMs
- Develope patient-specific models based off of MRI and CT data for subjects who received DBS treatment for dystonia

Acknowledgements

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References

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