Deep Brain Stimulation - Electric Field as a Predictor of Activation for Various Neuronal Elements

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I. INTRODUCTION

THE clinical benefit of deep brain stimulation (DBS) is largely dependent on the spatial distribution of the electric field in relation to brain anatomy. Models and simulations of DBS based on the finite element method (FEM) are commonly used to calculate and display the distribution of the stimulation field [1-5]. Results can be visualized by different electrical entities such as the electric potential V_T [V] the electric field E_T [V/mm] or the second difference of the electric potential AF_T [V/mm^2]. The challenge is to find an electric quantity that best relates to the activation in the brain function. Our approach is to combine detailed axonal simulations with field simulations to evaluate the relationship between the various electrical quantities and the axonal activation.

II. METHOD

Axon cable models representing three different outer diameters D were constructed and simulated in MatLab. The distribution of the electric potential in the vicinity of a DBS electrode (lead model 3389, Medtronic Inc., USA) surrounded by homogenous tissue was computed using an axisymmetric FEM model (COMSOL Multiphysics, COMSOL AB, Sweden). A physics-controlled mesh was applied with 0.05 mm side length elements close to the active contact in order to capture the strong electric field gradient. The distribution of electric potential in the tissue domain surrounding the electrode was calculated by solving the Laplace equation for steady current. The influence of DBS-stimulation pulse amplitude V_{DBS} [V] for the excitation of nerve fibers passing the electrode was simulated. Threshold-distance data for V_T, E_T, and AF_T were estimated as functions of V_{DBS} (0.5 – 5V; steps of 0.5) and D (2.5, 5.0 and 7.5 µm) for pulse width 60 µs, using the axon cable model.

III. RESULTS

The activation threshold V_T increases substantially with distance for all axon diameters, E_T increases slightly with distance for small fibers and remains approximately constant for larger fibers (Fig. 1). The threshold AF_T decreases by about 50% with distance for all fiber diameters. In conclusion, the electrical field strength appears a good predictor of activation for various neuronal elements over a range of clinically relevant distances from the DBS electrode.

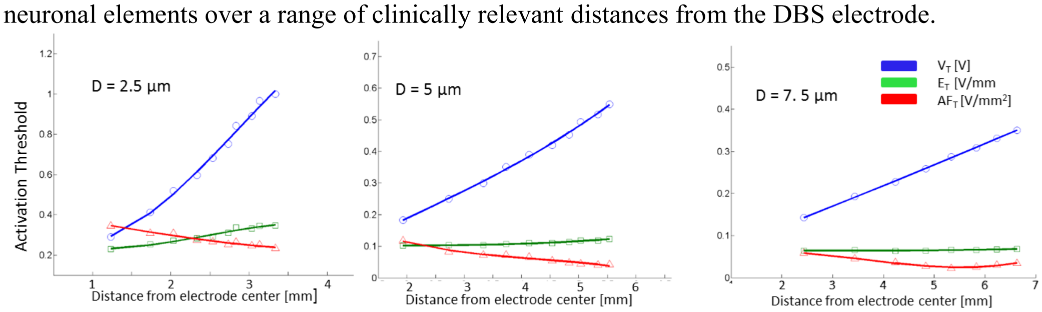

Figure 1. Activation threshold simulated for different DBS settings and axon diameters. Results are presented for V_T, E_T and AF_T.

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