Selectively stimulating neural populations in the subthalamic region using a novel deep brain stimulation lead design

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Deep brain stimulation (DBS) of the subthalamic nucleus (STN) is widely used in advanced stages of Parkinson's disease (PD) and has proven to be an effective treatment of the various motor symptoms. The therapy involves implanting a lead consisting of multiple electrodes in the STN through which continues high frequency electric pulses are delivered. The clinical outcome highly depends on the location of the electrodes within the STN. However, despite careful planning and precise stereotactic surgery, a placement error may occur. The state of the art (Medtronic) DBS lead containing four cylindrical contacts is only able to correct a placement error in dorsal-ventral direction. Therefore, a new lead design is developed which enables spatial steering of the stimulation field [1]. Martens et al. showed that the novel high resolution lead is able to steer the electric field in a homogenous isotropic volume conductor. However, the exact effect of the steering modes on the surrounding neurons in a more realistic anisotropic volume conductor is unknown. In this study, we calculated the electric field generated by a rectangular current-pulse waveform for different stimulation modes in a finite element model (FEM) of the electrode in the subthalamic region with volume conductivities based on diffusion tensor imaging (DTI). The stimulation effect of the imposed electric field is investigated on multi-compartment models (NEURON 6.2) of three distinct neuronal populations in the subthalamic region: the projection neurons within the STN, the globus pallidus internus (GPi) fibers of the lenticular fasiculus, and the internal capsule (IC) fibers of passage [2]. The latter is important in the assessment of the stimulation effect, because activation of the IC fibers generally causes severe side effects. In the analyses, we maximized the number of activated STN cells without stimulating the IC fibers to find the coverage of stimulation for different stimulation modes. In addition, we examined the selectivity of stimulating the STN cells without stimulating the IC fibers and GPi fibers. Our preliminary results indicate that it is possible to mimic the stimulation effect of the state of the art electrode with the high resolution lead. In addition, the spatial steering modes enable higher coverage of activation of STN cells without IC fiber stimulation and increases the ability to selectively stimulate the projection neurons of the STN (Fig.1). The clinical effect of the increased coverage and selective stimulation of the STN and GPi fibers needs further investigation. However, we believe that the model can be used as a tool for the neurologists and neurosurgeons in further research.

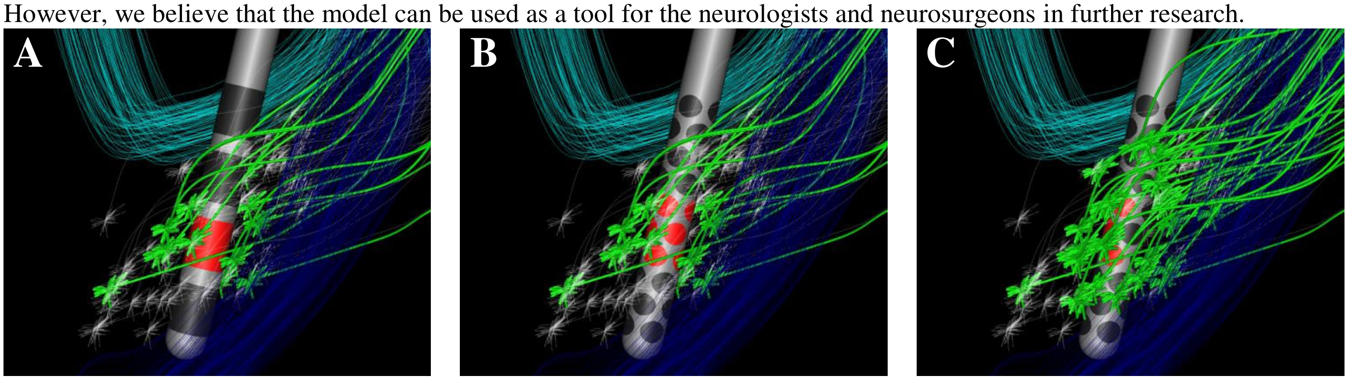

Figure 1, Model of the DBS lead in the subthalamic region, with the IC fibers in blue, the GPi fibers in cyan and the STN projection neurons in green (activated) or white (not activated). (A) Activation of STN cells (green) without IC and Gpi fiber activation by (A) the Medtronic 3389 DBS lead [1mA]; (B) the high-resolution lead stimulating in ring mode with 12 contact points [1mA]; (C) the high-resolution lead stimulating in medial direction with 4 contacts point [2mA].

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