Study of Electric Field Distribution in Deep Brain Stimulation

Guoya Dong, Tingyan Han, Dianli Lv, Shuai Zhang, Guizhi Xu, Weili Yan
Province-Ministry Joint Key Laboratory of Electromagnetic Field and Electrical Apparatus Reliability, Electrical School, Hebei University of Technology,
Tianjin 300130, People’s Republic of China
dongguoya@gmail.com

Abstract — The deep brain stimulation (DBS) effected using implantable neuron-stimulation systems has become an important symptomatic therapy in movement disorders such as Parkinson's disease. This study presents a head finite element model of deep brain stimulation to examine the electric field distribution. The head model using a geometrically accurate forward model includes two layers of scalp and brain with the correct conductivity parameters. By bipolar stimulation, the results indicate that incorporation of the human head model can alter the magnitude of the electric field when the electrode is deep within the brain, and the stimulation intensity and effective range of the activation volume are increased gradually with the gap of the electrode contacts growing.

I. INTRODUCTION

Deep brain stimulation (DBS) is a surgical treatment used to alleviate the symptoms of neurological disorders, most commonly movement disorders such as Parkinson’s disease, tremor and dystonia and increasingly for psychological disorders [1]. However, the mechanisms that govern these disorders are still not understood. It has been suggested that deep brain stimulation may cause activation or functional ablation of target neural structures, or that the stimulation may modulate neuropathological processes [2,3]. Generally believed that the stimulation can reduce or inhibit the electrical stimulation near the discharge of neurons, cell bodies of neurons directly inhibit or enhance the inhibition of excitatory synaptic nerve excitability, stimulation of these areas may activate axons of projection neurons, direct effect on the efferent fibers and the scope of the nearby neurons. Therefore, it is important to construct the finite element model of the real simulation head to analyze accurately the electric field distribution with different parameters sets. And it is useful to improve the safety and reliability of DBS treatment.

In the current study, a three-dimensional real model is constructed with two layers of scalp and brain for the human head. The electric field distributions induced by deep electrodes near the STN (subthalamic nucleus) region are analyzed with the COMSOL Multiphysics software.

II. MODELLING METHODS

A. The finite element model

Two dimensional T1 weighted MRI images with the digital communications protocol (DICOM protocol) were three-dimensional reconstructed after threshold segmentation by MIMICS software (Belgium Materlales company). The real physical model of the head was constructed with two layers of brain and scalp, as shown in Fig.1 (a).

The constructed physical model of the head was then inputted into COMSOL Multiphysics 3.5a software. Based on deep brain stimulation theory and Medtronic 3389 Electrode structural parameters for DBS [1], a bipolar electrode with two contacts was placed near STN (subthalamic nucleus) region in the deep brain, shown in Fig.1 (b), the regions in white are insulating parts.

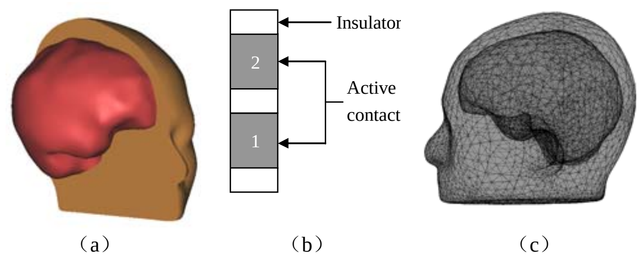

Fig.1 (a) Reconstructed head model. (b) Deep electrodes. (c) Mesh system.

The modeling package COMSOL Multiphysics 3.5a was used to create a three-dimensional finite element model of the human head. The finite element method allows us to model a three-dimensional structure by discrete it into smaller volumes, in order to estimate the solution to a partial differential equation, which describes the electric field distribution over a bounded volume. The head and brain were meshed into 68,666 tetrahedral elements and 12998 nodes using a Delaunay meshing algorithm within COMSOL, as shown in Fig.1 (c).

B. Quantification

The potential distribution induced by stimulation was calculated by solving the Laplace equation:

$$\nabla \cdot \sigma \nabla \phi = 0 \tag{1}$$

where ϕ is the potential (measured in V), and σ is the conductivity (measured in S/m) and ∇ is the gradient differential operator. It was assumed that the region of interest has no space charge density and that there were no internal current sources in the tissue. The mean conductivity values of the tissue were defined based on previous biological studies, which the brain is 0.25S/m and the outer layer of the head is the value of 0.44S/m [4].

The simulation results are presented as the potential distribution ϕ obtained directly from Poisson’s equation, or as the electric field E distribution, where E is calculated by the following equation:

$$E = -\nabla \phi \tag{2}$$

In order to simulate the deep stimulation, the active contacts were set to the desired stimulating potential in volts, and the outer boundary of the human head tissue was constrained to 0V via Dirichlet boundary conditions. The insulating parts of the implanted electrode were bound using Neumann conditions, constraining the derivative of the electric potential through these boundaries to be zero, i.e. there is no current flow through these boundaries.

III. RESULTS

A. *Electric field distribution with bipolar stimulation*

The stimulating potentials on the surface of the two contacts of the electrode were set to ± 1V DC, respectively. The distance between these two electrodes is H1=0.5mm. The simulation results near the STN region were displayed in Fig.2. Note that electric field E is a three-dimensional vector and was plotted using its 'norm' in Figures.

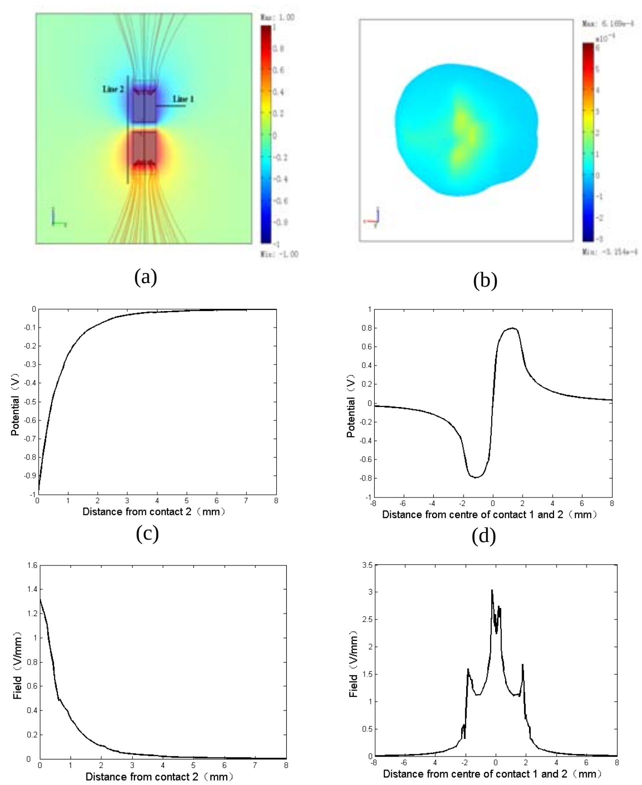

Fig.2 The distribution of potential and electric field. (a) The potential distribution and electric field line around the bipolar electrodes. (b) The potential distribution on the bottom of brain surface. (c) and (d) The potential distributions at the points in line 1 and line 2 (0.2mm distance apart from the electrode contact surface), respectively. (e) and (f) The electric field distributions at the points in line 1 and line 2, respectively

B. *The effect of distance between two contracts on electric field distribution*

The distance between electrode contacts are defined as H1=0.5mm, H2=2.5mm, H3=4.5mm. The stimulating potentials on the surface of the two electrode contacts were all set to ± 1V DC for the three cases. The simulation results are shown in Fig.3.

As shown in Fig.3 (a), the potentials at the points in line 1 are decreased with the gaps of the two electrodes increasing. In Fig.3 (c) and (d) show results at the points in line 2. With the gap of the electrode contacts growing, the stimulation intensity and effective range of the activation volume are increased gradually, while the electric field decreased around the gap.

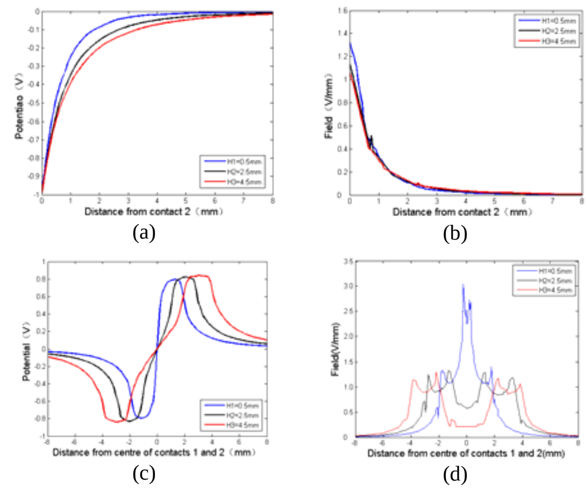

Fig.3 The potential and electric field distributions around the electrodes with different distances of electrode contacts. (a) and (b) The potential and electric field distributions at points in line 1, respectively. (c) and (d) The potential and electric field distributions at points in line 2, respectively.

In the final full paper, more improved simulation results will be presented including the results for the real head with four layers, i.e., scalp, skull, CSF, brain. And the comparison of electric field distribution between the real head model and four-shell spherical model will be carried out.

IV. ACKNOWLEDGEMENTS

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