International Journal of Computational and Experimental Science and Engineering
(IJCESEN)
Vol. 1-No.1 (2015) pp. 5-7

www.ijcesen.com

Special Issue for "International Conference on Computational and Experimental Science and Engineering" (ICCESEN-2014)"

Simulation of Electrical Stimulation of Layered Retina with Bipolar Electrode Configuration and Temperature Change on the Retina

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Keywords
Bipolar electrode, epiretinal implants, electrical stimulation, finite element analysis, visual prosthesis

Abstract: Visual perception may be completely lost due to some degenerative retinal diseases in time. Degenerative retinal diseases, such as Age Related Macular Degeneration (AMD) and Retinitis Pigmentosa (RP), are damaged to the photoreceptor layer of the retina, but visual cortex of the brain and half of the inner structures of the retina remain intact. Visual prosthesis systems are based on electrically stimulation of remaining nerve cells by placing stimulation electrode array and necessary electronics on the retinal tissue. In the first part of this study, two-dimensional retina model, which use bipolar electrode configuration system in which stimulation current is passed between two electrodes, thus an activation region is created, is developed. Solution is made using Finite Element Analysis (FEA). Electric field distribution and current density are investigated depending on the potential difference. It is showed that maximum electric field intensity increases with the rise of potential difference, moreover, electric field enlarges over the retina tissue. Current density is much higher at the positions where edges of the stimulation electrodes are. This means that nerve cells in deeper regions could be stimulated. Then, second part includes the investigation of temperature change on the tissue induced by power dissipation of the electronics and stimulation electrode arrays. Results showed that temperature change has an increasing trend with the rise of power dissipated. Change in the temperature near the electrode and activation region is more sensitive, so temperature change diminishes in the regions away from heat source.

1. Introduction

In recent years, developments in the field of biomedical engineering make possible to investigate electrical stimulation of nervous system parts resulting in many software and hardware system designs and implementations. Development of visual prosthetics has gained momentum in recent years with multidisciplinary studies all over the world despite it has dense nerve network and complex physiological structure.

This study includes two parts. First part aims to provide computational retinal stimulation model, which is stimulated with bipolar electrode configuration which uses two neighbor electrode and generates activation region between them, to examine stimulation results such as electric field intensity and current density. Second part includes the investigation of temperature change on the tissue, which is assumed that retina is homogeneous and isotropic, induced by stimulation electrode array. All solutions are made by finite element analysis.

2. Simulation of Computational Layered Retina Stimulation with bipolar electrode configuration

Biphasic and monophasic waveforms are used in many applications. Current pulses are defined with charge delivered, charge density, current amplitude, current density and pulse frequency. Neuron activity recorded as action potential shows the firing of single neuron. Recording process is performed with the microelectrodes placed being closer to the neurons whose activity is recorded. Electrical stimulation initiates with the depolarization of the membranes of cells which are stimulated. This occurs with depolarization provided with ionic current flow between at least two electrodes which are close to the cells. This part of the study presents the development of the layered retina which is stimulated with bipolar electrode approach. Potential difference, 0.5, 1, 1.5, 2 Volt, is applied between electrodes and electric field distribution and current density are investigated. Retina tissue is stimulated under the mentioned conditions and results are given in Fig. 2 (A).

3. Investigation of temperature change on the tissue depending on the power dissipated

One of the most important problems of long-term visual prosthesis systems is the temperature change on the tissue. Electrical stimulation of the tissue causes increase in the temperature, which is categorized into two main parts, namely Joule heat and metabolic reactions [1, 2]. Joule heat forms in the presence of electric field. The properties and stimulation parameters such as amplitude, frequency, pulse width determine the temperature change. High temperature change is much risky because it could be lead to nerve cells' death [3]. It is stated that increase of 3°C more than normal body temperature could cause various physiological abnormalities and a number of defects in tests conducted using guinea pig, rat [4]. So, investigation of these effects in silico provides great benefits. Stimulation electrode array is a kind of heat source due to power dissipated and causes temperature change. In this part of the study, to investigate investigation of temperature change depending on the 10 mW, 11 mW, 12 mW, which is a power dissipation of an important implant system with 60 electrodes, 13 mW power dissipated, realistically modeled retina model that it can deliver the heat every direction like real heat transfer mechanism of the live tissue is formed as shown in Fig. 1 [5].

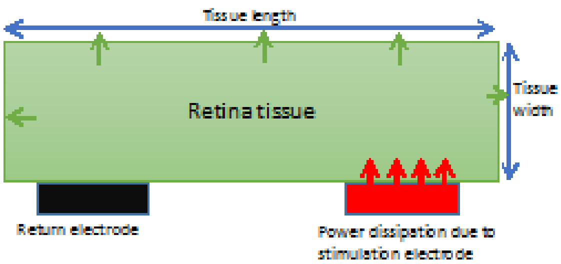

***Figure 1.** Retina model to investigate temperature change with heat transfer mechanism.*

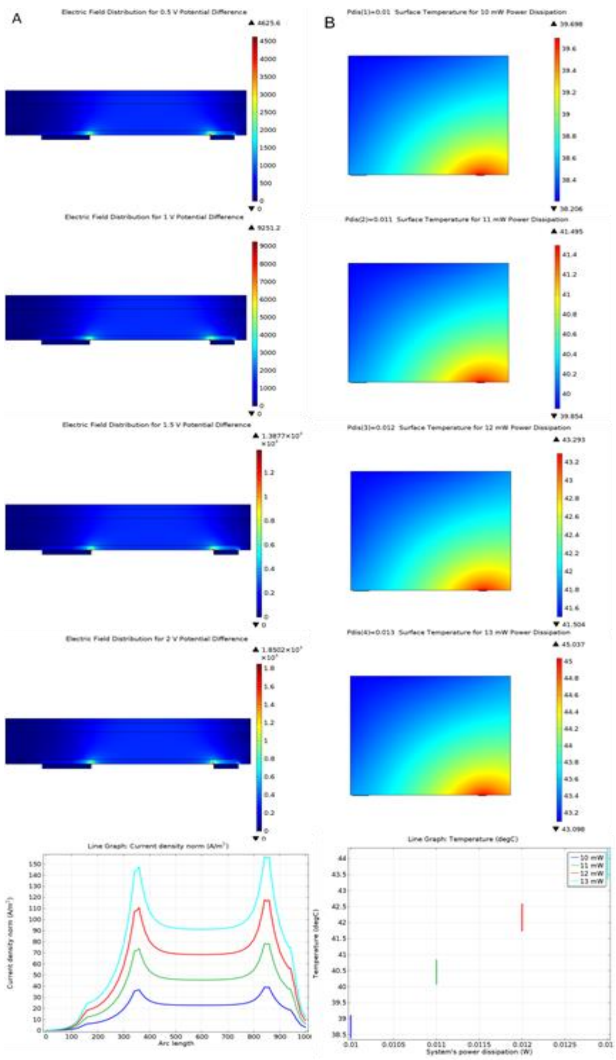

***Figure 2.** Retina model to investigate temperature change with heat transfer mechanism.*

Some assumptions are made such as, tissue is homogeneous and isotropic. Like stimulation model, heat transfer is also investigated under stationary condition. Heat transfer is based on Pennes bioheat equation by

$$\nabla.(-\mathrm{k}\nabla \mathrm{T}) = \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \quad (1)$$

where k, ρ_b, C_b,ω_b, Q_{met},Q_{ext} represent thermal conductivity (W/mK), density (kg/m3), specific heat capacity which is the amount of energy to produce change of a unit temperature (J/kg.K), perfusion rate which shows volume of blood per second flowing through a unit volume of tissue (1/s), heat source of metabolism and external heat source (W/m3) respectively. Thermal properties, which differs greatly depending on the measurement conditions, are obtained from certain literatures and model dimensions are given in Table 1 [6, 7].

Table 1. *Parameter values and units*

Parameter	Value (Unit)
Initial temperature	36°C
Thermal conductivity	0.528 (W/mK)
Density	1040 kg/m3
Tissue width	8 mm
Tissue length	10 mm
Heat capacity	3650 J/(kgK)

It is seen that as the potential difference increases the maximum electric field intensity also increases. Additionally, the region of electric field enlarges. This means that nerve cells in deep regions of the tissue could be stimulated with the increasing stimulation amplitude. In comply with the bipolar electrode configuration concept, an activation region is created between electrodes, which provides efficient stimulation.

It is seen in Fig. 2 (B) that when the power dissipation increases the temperature change also increases and shows bigger region near the electrode. Maximum heat is observed at the edges of the electrode. Source region has the primary role to be effected tissue. As it is moved away from the electrode temperature change diminishes.

4. Conclusion

Development of realistic simulation models provides great benefits. The implant, a microelectrode array (MEA), which will be placed to the retinal tissue is a source of heat because of power dissipation. This heat leads to temperature change around the MEA, and it has to be within allowable limits to avoid thermal damage to the tissues. Simulation models are useful to test whether the system are within these limits, or not. Thus, the system can be revised if necessary.

In the future, it is planned that time dependent stimulation pulses are simulated using computational retina models with different electrode configuration. Time dependent stimulation pulses are monophasic and biphasic pulses, which are the most common stimulation pulse type used in retina stimulation. Besides, modelling results will be incorporated with in vitro animal experiments with rabbit eyes which is another project we have been conducting for the last 6 months.

References

[1] Chang, “Finite element analysis of hepatic radiofrequency ablation probes using temperature-dependent electrical conductivity,” Biomed. Eng. Online, 2-12, 2003.

[2] S. Tungjitusolmun, E. J. Woo and H. Cao, “Finite element analyses of uniform current density electrodes for radio-frequency cardiac ablation,” IEEE Trans. Biomed. Eng., 47 32–40, 2000.

[3] B. Bennetts, M. L. Roberts, A. H. Bretag and G. Y. Rychkov, “Temperature dependence of human muscle ClC-1 chloride channel,” J. Physiol., 535 83–93, 2001.

[4] T. M. Seese, H. Harasaki, G. M. Saidel, and C. R. Davies, “Characterization of tissue morphology, angiogenesis, and temperature in the adaptive response of muscle tissue in chronic heating,” Lab. Investigation, vol. 78, pp. 1553–1562, 1998.

[5] K. Gosalia, J.Weiland, M. Humayun, and G. Lazzi, “Thermal elevation in the human eye and head due to the operation of a retinal prosthesis,” IEEE Trans. Biomed. Eng., vol. 51, no. 8, pp. 1469–1477, 2004.

[6] C. M. Collins, M. B. Smith, and R. Turner, “Model of local temperature changes in brain upon functional activation,” J Appl. Physiol., vol. 97, pp. 2051–2055, 2004.

[7] C. W. Connor and K. Hynynen, “Patterns of thermal deposition in the skull during transcranial focused ultrasound surgery,” IEEE Trans. Biomed. Eng., vol. 51, no. 10, pp. 1693–1706, Oct. 2004.