Magnetic Neural Stimulation of Peripheral Nerve: A Study for Optimum Spatial and Temporal Electric Field Distribution

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Magnetic stimulation of peripheral nerves is an evolving research that leads to contactless activation of the axons. Traditionally, this technique was applied for the design of transcranial stimulators and was subsequently used in clinical studies for the treatment of epilepsy, chronic pain and mood disorder. Despite its success, the large dimension of the magnetic stimulator and the significant energy requirement to elicit neural activity hindered the ability of magnetic stimulators to become a viable candidate for the implantable systems. Compared to electrical neural stimulation, magnetic stimulators require ~10^8 times higher energy and ~50 times larger electrode (or coil). Therefore, there is a need to research strategies to minimize the energy and dimensions of magnetic stimulators.

The stimulation threshold for the magnetic stimulator depends on the spatial and temporal distribution of the induced electric field in response to the coil's time varying magnetic field. Previously, multiple studies used animal experiments to indentify the prominent features of the induced field that influence the stimulation threshold (E. Corthout et. al., Exp Brain Res., 2001). However, limited number of experiments performed in these studies did not provide optimum simulation parameters. To search the vast feature space of the stimulus pulse, simulations were performed for the homogenous tissue model and stimulus energy were calculated as a function of magnetic coil's turns and radius (K.-H. Hsu et. al., IEEE TBME, 2003). However, the results of this study were not validated using the experiments, which leaves an opportunity for the simulation model that can be validated using animal experiments. Recently, we developed a μm-scale computational model of rat's multifascicular sciatic nerve and predicted the stimulation thresholds for multiple solenoid coils within 95% confidence interval of the experimental value. In this work, we used this validated model to identify the spatial and temporal profile of the induced electric field that can reduce the stimulation threshold and coil's dimensions.

To cause neural activation in a myelinated axon, the transmembrane potential across the node of Ranvier needs to be increased above the threshold value. The magnitude of this threshold depends on the spatial profile of the induced electric field. In this work, stimulation thresholds were identified for different spatial profiles (i.e., Gaussian and its derivatives, sine, rectangular, etc.) of the field. This study suggests that a sinusoidal profile with spatial period of eight nodes achieves the lowest stimulation threshold. The optimal temporal distribution required the identification of the frequency for which the active ion channels of the nodes respond effectively. It was shown that for the stimulus frequency of 5 kHz, the electric field threshold is lowest.