Ultrasound Neuromodulation: Field Overview and Observations in the Vagus Nerve of a Rat

E. Juan[1]
[1]UPR-Mayagüez, Mayagüez, PR

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Eduardo J. Juan
Department of Electrical Engineering, University of Puerto Rico – Mayagüez

Introduction: The use of focused ultrasound waves to modulate neural structures has gained recent interest due to its potential in treating neurological disorders noninvasively and with good spatial resolution. Research performed on ultrasound neuromodulation can be divided into two major categories: (1) one that focuses on the central nervous system (CNS) and (2) another that focuses on the peripheral nervous system (PNS). This presentation provides a summary of the most recent work on ultrasound neuromodulation, areas of opportunity in this field, as well as preliminary observations of ultrasound neuromodulation on the vagus nerve of a rat. The potential application of vagus nerve ultrasound neuromodulation for the treatment of epilepsy will also be presented.

Materials and Methods: The left cervical vagus nerve of an anesthetized Long Evans rat was surgically exposed. Stimulating and recording cuff electrodes were carefully placed on the vagus nerve. The nerve was electrically stimulated until evoked compound action potentials (CAPs) were recorded. A 1.1 MHz focused ultrasound transducer was used to insonify the vagus nerve between electrodes. Ultrasound energy was applied at spatial-peak, temporal-average intensities (I_{SPTA}) that ranged from 13.6 to 93.4 W/cm^2. The amplitudes of the compound action potentials were then measured before, during and after ultrasound exposure.

Results and Discussion: The percent change in CAP amplitudes, as taken from the change in amplitude just before and after fifteen seconds of ultrasound exposure, were plotted as a function of I_{spta}. Figure 4 shows the percent amplitude change for both peaks, and the temperature increases of acoustic gel, as a function of I_{spta}. It can be noticed that the trend is to have increased changes in amplitude as the I_{spta} is increased. An exception to this trend was observed at an I_{spta} of 68.0 W/cm^2, where the change in CAP amplitude was less than those observed at lower I_{spta} values.

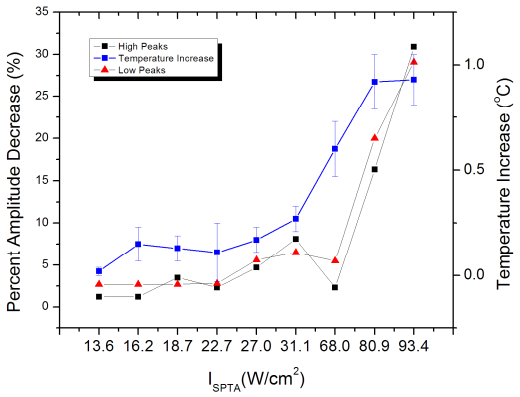

Figure 1. Percent amplitude change for both CAP peaks as a function of I_{spta}. This plot also shows the observed acoustic gel temperature changes (calculated as the temperature difference before and after 15 seconds of ultrasound exposure) for each combination of acoustic parameters used in the experimental trials.

Conclusions: Ultrasound neuromodulation is a promising field with many potential applications in the noninvasive treatment of neurological disorders. Ultrasound neuromodulation of the vagus nerve was observed in this preliminary study using focused pulsed ultrasound at a frequency of 1.1 MHz. Results of this preliminary study suggested that there is a proportional relationship between acoustic intensity and the level of inhibition. Additional studies will be needed to better understand the relationship of ultrasound parameters (pressure amplitude, carrier frequency, pulse repetition frequency and duty cycle), on vagus nerve neuromodulation. The goal of these future parametric studies should be to establish mathematical expressions that help predict nerve responses to different ultrasound parameters, such as in the case of electrical stimulation, where at least two forms of strength-duration curves are known.