Measurement of Cortical Stimulator Outputs in Simulated Electrode-Tissue Interface

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CNS 2018 ANNUAL MEETING
HOUSTON, TEXAS
OCTOBER 6-10, 2018

Keck School of Medicine of USC

Introduction

Neurostimulation is widely used for the treatment of movement disorders and medically-refractive epilepsy. Stimulators are used both in the intra-operative as well as chronically-implanted state. Here we measure and compare two commercially available cortical stimulator outputs using a simulated electrode-tissue interface. We characterize charge balance (the balance between positive and negative charges built up at the electrode-tissue per measurement period) of the waveforms because of the potential clinical implications of non-charge balanced stimulation.

Methods

The electrode-tissue interface was simulated using a circuit with a single 1 kOhm resistor (Wei et al. 2009) in parallel (Holsheimer et al. 2000) with a 3.3 μF capacitor to represent the tissue resistance and electrode capacitance, respectively. Cortical stimulator output was measured using a National Instruments Data Acquisition Device (USB 6343). The voltage change across a 220 Ohm shunt resistor was converted to current as each stimulator is current regulated. Two cortical stimulators were tested: the Natus Nicolet Cortical Stimulator ("Natus") and Grass Technologies S12X ("Grass"). In order to collect data across a range of clinically-used stimulation parameters, we varied the current (0.2-10 mA), pulse duration (100-1000 μs), and the pulse frequency (5-100 Hz). Each combination of parameters was recorded over 5 seconds. The charge balance was measured as a ratio of the total positive charge per test divided by the total negative charge per test. For each stimulator, a one -sample t-test was used to compare the measured charge ratio across all parameters (N = 32 for Grass and N = 28 for Natus; one combination that was available on Grass was not available on Natus).

Results

Across all stimulators and stimulation parameters, there was significantly more positive charge output from the stimulator than the negative. There was an average of 17.6% more positive charge for the charge ouput for the Natus Stimulator ($p < 0.006$). Below are representative stimulator outputs.

Natus Stimulator Charge Ratio at 1mA Stimulation

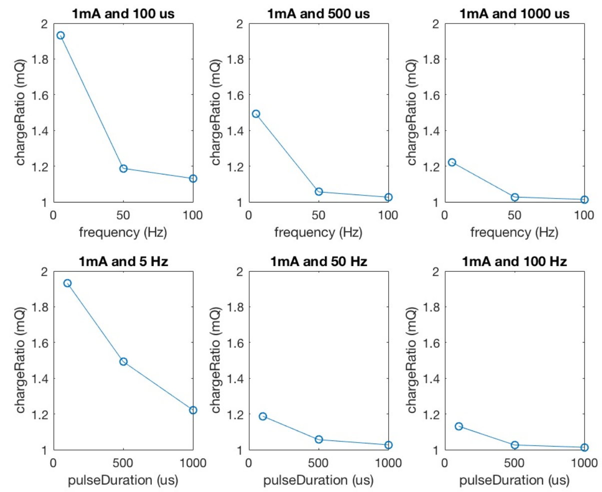

Figure 1: Natus Stimulator Charge Ratio across varying pulse durations and frequencies

Grass Stimulator Charge Ratio at 1mA Stimulation

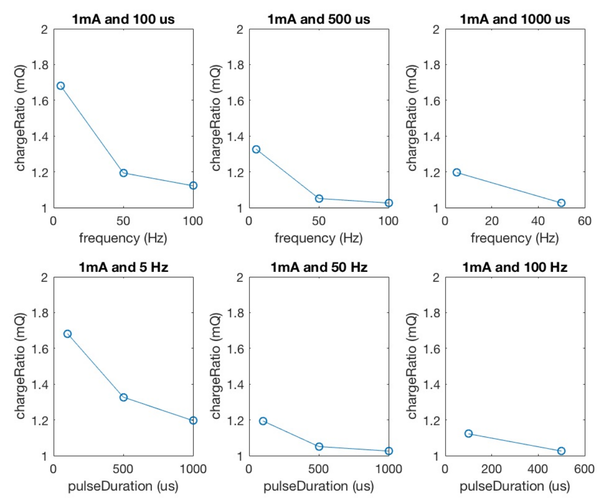

Figure 2: Grass Stimulator Charge Ratio across varying pulse durations and frequencies

Representative Waveforms from Natus and Grass Cortical Stimulators

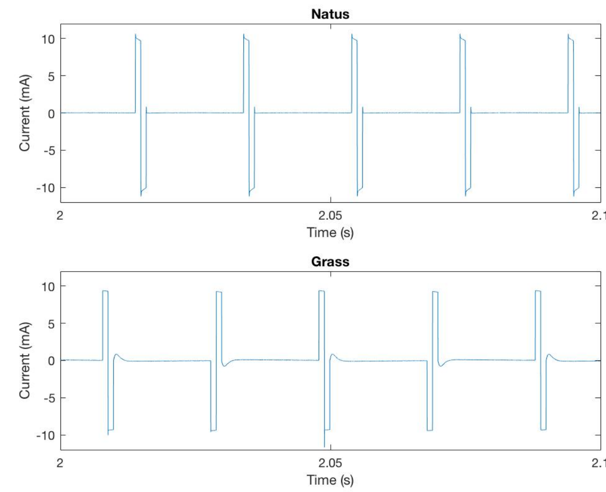

Figure 3: The following stimulator settings were used: 10mA current, 1000μs pulse duration, and 50Hz frequency

Conclusions

There are significant differences between the selected and measured output for the two commercially-available cortical stimulators that were tested. Our results suggest that a charge imbalance is building up to a significant degree even over the short time periods in which we tested the devices. Further investigation into the long-term effects of such stimulation on the electrode-tissue interface is warranted. Characterization of these same properties in chronically-implanted devices could be crucial to understanding how to maximize clinical efficacy as well as minimize side effects to ensure patient safety.

References

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2. Holsheimer J, Dijkstra EA, Demeulemeester H. Nuttin B (2000a). Chronaxie calculated from current–duration and voltage–duration data. J Neurosci Methods. 97:45–50.