Short-term impedance variability during programming sessions in a pre-clinical model of deep brain stimulation

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Introduction

In DBS programming, the clinical standard of care is often to perform a monopolar review (MPR) upon activation of the stimulator, in order to determine efficacy and side-effect thresholds for all contacts on any lead of a DBS system (Volkman et al., 2002). The MPR informs the selection of first clinical program, with which the patient is sent home in the ON condition.

We hypothesized that impedances change over the course of the MPR and initial programming session. Existing work (see Lempka et al., 2010) has demonstrated that DBS electrode impedance changes as a function of time and stimulation. For a voltage-controlled DBS system, such impedance changes could result in changes in stimulation (McNeal, 1976; Butson, 2006), and thus could result in variability of measured efficacy and side effect thresholds during a monopolar review.

Methods

Two (2) farm pigs were implanted with bilateral active DBS leads. A Boston Scientific Vercise DBS lead with standard DBS contact sizes (1.5mm height, 1.3mm diameter) was placed in either the left or right frontal lobe of each animal, and an experimental lead with non-cylindrical geometry including smaller contact sizes was implanted in the contralateral side.

A monopolar review was performed 23-24 days post-implant for both animals. During this MPR the animals were exposed to a series of stimulation settings intended to simulate the measurement of efficacy and side effect thresholds in a clinical setting. Impedances on all contacts were measured throughout this procedure every 45 seconds. The short-term evolution of impedance after performing the MPR was also investigated by turning one contact of both leads ON at putative nominal settings (3mA, 130Hz, 60μs) and sampling impedance approximately once per minute for an hour. Impedance was also tracked in the OFF condition for one hour prior to running the MPR protocol. Stimulation had been OFF for over 12 hours prior to the first OFF block.

Results

Impedances varied by up to 44% (peak-to-peak) over a time scale of minutes, and could both increase and decrease during the programming session. The maximum increase observed on a standard-size contact was 29% above the baseline at the beginning of the monopolar review, with the entire increase occurring over a 10 minute period while the amplitude on the contact was being adjusted. The same contact then rapidly decreased in impedance while other contacts were being stimulated later in the monopolar review, settling to a level 15% below baseline. Notable changes in impedance were observed across all contacts. Differences between contacts in the magnitude, direction, speed, timing, and duration of impedance changes were correlated with several variables, including whether the electrode was active or passive, whether it neighbored an active or passive electrode, the amplitude of stimulation delivered through the electrode, its temporal relation to other stimulation, and the size of the electrode.

![Figure 1. Putative (contrived) Monopolar Review (MPR). Distal contacts of the lead were contrived to be ‘within target’, thus higher amplitudes were explored. Moving from distal to proximal contacts, the maximum amplitude was lowered. Each contact was active for the same number of data points (10), or for approximately 8 minutes. A single contact was active at any time.](image1)

![Figure 2. Impedance on all contacts during MPR. Impedance on active contacts both increased and decreased when the contact was active. Impedance on contacts neighboring an active contact also appears to deviate from baseline.](image2)

![Figure 3. Impedance on all contacts during MPR; animal 2. Demonstration of repeatability is made using standard DBS lead. Block 3 experimental lead is withheld due to the proprietary nature of the experimental lead.](image3)

![Figure 4. Impedance on all contacts during ON block for small contacts lead. Impedance on the active contact increased by ~40% over ~10 minutes, then decreased.](image4)

![Figure 5. Impedance on all contacts during ON block for standard DBS lead. Impedance on the active contact decreased by ~7% over ~60 minutes. Note difference in scale for figure 4.](image5)

Conclusions

Previously, researchers (Lempka, 2009, 2010) have proposed that instability in impedances could be partially responsible for the frequent need to reprogram stimulators in DBS patients postoperatively. The impedance changes observed in this animal model offer a plausible scenario by which this could occur. Changes in impedances would be expected to result in changes in current at the electrode for a voltage-controlled DBS system, such that any thresholds for efficacy or side effects measured during the monopolar review would be different than thresholds after the programming session is complete. Impedance changes over a brief programming session might therefore compromise the selection of stimulation parameters for long-term DBS. Further studies should explore whether the same short-term impedance changes can be observed during a monopolar review in a clinical setting.

*Figure 3.* Impedance on all contacts during MPR; animal 2. Demonstration of repeatability is made using standard DBS lead. Block 3 experimental lead is withheld due to the proprietary nature of the experimental lead.

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**Table 1. Describing the order of stimulation in each animal**

<table>
<thead>
<tr>
<th>Protocol Block</th>
<th>Block 1</th>
<th>Block 2</th>
<th>Block 3</th>
<th>Block 4</th>
</tr>
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<td>MPR</td>
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