THE ART AND SCIENCE OF DEEP BRAIN STIMULATION PROGRAMMING

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General Introduction to Programming Basics
While each disorder treated with DBS presents the programmer with a unique set of challenges, the basic approach to programming is essentially the same. It thus makes sense to begin with some fundamental programming guidelines that will apply across the board. Though a number of new systems and innovations are either currently available, we will for practical purposes limit ourselves to the most commonly used Medtronic Activa © systems with occasional reference to the newer St. Jude Infinity System ©.

ELECTRODES: There are two basic Medtronic options when it comes to electrode spacing, the 9957 and the 9959, the difference being the span between the four electrodes, which is 10.5mm with the 9957 and 7.5mm with the 9959. From a programming perspective, the difference is seldom dramatic since the span of either should prove more than adequate when considering the length of the STN and GPI is typical only about 5mm in most cases. Both have four electrodes, which by convention are labeled 0, 1, 2, 3 with 0 being the deepest (most ventral) and 3 being the uppermost (most dorsal). When both the right and left leads are attached to a single dual-channel implantable pulse generator, one lead will be designated 0 through 3 while the other will be designated 8 through 11 (again with 8 being the most ventral). Whether the left or right lead is designated 0-3 or 8-11 will depend on how the surgeon connects them. When two separate IPGs are used, both leads are designated 0 through 3 and it is incumbent on the programmer to make sure they consistently differentiate between the two sides, ideally by noting the left and right serial numbers to differentiate them. For the newer St. Jude electrodes, there are similarly 4 electrodes but they are numbered 1-4 with 1 being the deepest/most ventral and 4 being the highest/most dorsal. The middle two electrodes, #2 and #3, are directional in nature and subdivide into three segments (e.g., 2a, 2b and 2c). One, two or all three of the segments can be utilized for these. Current is directed through the active segments only. Irrespective of the system being used, I try to make a habit of always starting with the left brain side then moving to the right to keep my notes consistent. For clarity, I always refer to the stimulated side, not the body side; that is to say, when I talk about the left side, I am talking about the left IPG (or left STN, VIM or GPI) that stimulates the left brain and affects the right body. Go over this with the patient so you're both on the same page. It prevents confusion when the patient calls to report problems on the "left side."

Implantable Pulse Generators (IPGs): The implantable pulse generator, also known as the case and abbreviated "C" when programming, is the battery source and connects via an extension wire to the electrodes in the brain. It is through the IPG that you will interface with and program the electrodes. There are currently three basic choices for IPGs, all manufactured by Medtronic: the single channel Activa SC, the dual channel Activa PC, and the dual channel Activa RC Rechargeable. When patients are likely to receive bilateral stimulation, they thus will usually have either two SCs (one SC for each side) or one PC to which both leads connect. The rechargeable model is a dual channel device and so also involves one IPG that receives both electrodes from both sides of the brain. The Infinity IPGs can be used to accept unilateral or bilateral electrodes. There is not currently a rechargeable Infinity model. The Boston Scientific model, available in Europe, is solely a rechargeable IPG. Whatever and wherever the IPG, though, the programming principles remain the same.

PROGRAMMING PARAMETERS:

Polarity: Each of the four electrodes, also referred to as contacts, can be used singly or in combination with the others. The active electrode(s) is designated as the cathode or negative (-) charge with the anode (+) being either the IPG or another electrode. When the IPG – or "case" - is the reference, it is termed monopolar stimulation. Thus, if you are using electrode 0, the charge is referenced against the distant IPG and would be described as "case positive, electrode 0 negative." When another electrode is used as the reference, it is termed bipolar with examples including 2+1- where electrode 2 serves as the anode and 1 as the cathode. If the polarity was reversed and 2 became the active contact, it would be 2-1+.With both monopolar and bipolar configurations, multiple contacts can be employed. Examples include C+1-2- 0+2-3-. In brief, monopolar stimulation provides a more uniform sphere of stimulation than bipolar stimulation because its anode is relatively distant (i.e., the IPG located in the chest rather than a neighboring electrode a couple millimeters away). Bipolar stimulation tends to be "tighter" and conforms differently according to the proximity of the reference in relation to the active contact. In general, we typically start out with monopolar stimulation and move to bipolar when side effects necessitate a narrower or more sculpted area of stimulation. There are advocates for starting with bipolar since it is typically better tolerated but the general preference is still to start with monopolar and shift to bipolar when necessary. In regards to the Infinity system, the principle of monopolar versus bipolar is the same. The added feature, as discussed above, is the directional component of the middle two electrodes. These can likewise be programmed in monopolar mode using any or all of the three segments (e.g., C+2a- or 2a+2b- or C+2a-b- and so on). Segmented electrodes do not necessarily have to be used as "segments" with the entire group essentially turning into a traditional omnidirectional electrode (e.g., C+3a-b-c- is for intents and purposes, equivalent to C+3-).

Voltage/Pulse Width/Frequency:

Voltage: Voltage (v) is the parameter that tends to get the most attention. Voltage is the difference in electric potential energy generated between two points (in our case, between the active electrode(s) and the ground, which can be the IPG or another electrode) and is generated by electric current moving through a magnetic field. In DBS, the range of voltages is typically between 1 and 4 volts with 3.6 being an historical line in the sand above which battery drain doubled. This is now less an issue with newer batteries but remains a reasonable landmark for clinical efficacy in most cases. Rarely does one require voltages above 6 volts and caution should be exercised when going much beyond that. In essence, increasing the voltage increases the energy delivered through the active electrodes and, as a result, steadily increases the area of stimulation around that electrode. The Medtronic IPGs also allow for programming in constant current, or amperes. The newer St. Jude and Boston Scientific systems work exclusively in constant current (mA). To review, the difference between an amp and a volt is that an amp is the measure of the amount of electrons moving through a circuit and a volt measures how much force those electrons are under. While there are theoretical advantages to working in constant current, it is presently unclear whether there is any clinical advantage in working with micro-amps versus volts. Since most of the literature is in volts, it remains the standard but perhaps further exploration will reveal practical differences between the two.

Pulse Width: Pulse width (PW) is the duration of a pacing impulse and is measured in microseconds (us). The longer (or higher) the PW, the longer a given amount of stimulation is being delivered through an electrode. For DBS, the PW employed is usually 60, 90 or 120us though occasionally higher, particularly for dystonia. Because the intervals between PW options are larger than those with either voltage or frequency, jumping from 60 to 90 or 90 to 120 tends to represent a fairly significant increase in stimulation effect (and battery drain).

Frequency: Frequency (F) refers to the number of cycles per unit of time. In DBS, the unit of time is Hertz (Hz) where 1 Hz means an event occurs once per second. The typical frequency ranges in DBS are between 130-185 Hz though there has been some interest in low frequency (60-90Hz) for both gait in Parkinson's and for management of dystonia.

The Initial Programming Session:

The basic tenets of DBS programming are the same irrespective of the disorder that is being targeted. That's comforting because with thousands of programming permutations, it's helpful to have a consistent approach that allows you to narrow in on the optimal settings with some efficiency.

The initial programming session is something like figuring out a jigsaw puzzle. You're presented with a bunch of disconnected pieces of information that you have to synthesize. In this light, it's helpful to gather whatever pieces you can from the operative experience. Knowing about intraoperative challenges and responses to test stimulation, reviewing post-op imaging results with the neurosurgeon and having some familiarity with pre-operative symptom severity is optimal. Most centers wait until at least 2 weeks after the implantation of the DBS leads before programming. This is because some patients experience a strong microlesion effect immediately after the surgery where their symptoms dramatically improve just from the placement of the electrodes. This benefit typically starts to wane by the 2 week mark, making it easier to gauge the impact of stimulation. When practicable, it is best to perform the initial programming off all Parkinson's, dystonia or essential tremor medications, preferably for at least 12 hours, so the effect of stimulation can be appreciated in isolation. Select the one or two features that respond most immediately to stimulation and that will not fatigue from repeated testing (e.g., rest tremor or rigidity in Parkinson's, spiral drawing in essential tremor, particular tasks with dystonia).

Programming typically begins with the most ventral contact, setting the PW and F at predetermined levels (usually 60ms and 130Hz for STN Parkinson's; 90ms and 130Hz for GPi Parkinson's and dystonia; 60Hz and 130 Hz for VIM ET though exact preferences vary) and slowly build up on the voltages (or amperes), documenting the benefits and side effects carefully along the way.

In the teaching session we will review how to apply these basic principles to programming patients with essential tremor, Parkinson's disease and dystonia. We will explore the anatomy of the structures being stimulated and review how this impacts the programming approach. We will also review practical strategies for overcoming common challenges.

Further Reading and References for the talk:

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- Pollak P, Krack P, Fraix V,Mendes A, Moro E, et al. Intraoperative Micro- and Macrostimulation of the Subthalamic Nucleus in Parkinson's Disease, *Mov Dis,* Vol. 17, Suppl. 3, 2002, pp. S155–S161
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- Kumar R, Methods for Programming and Patient Management with Deep Brain Stimulation of the Globus Pallidus for the Treatment of Advanced Parkinson's Disease and Dystonia. *Mov Dis*, Vol. 17, Suppl. 3, 2002, pp. S198–S207
- Two initial programming videos available at: http://www.neuromodulation.org/resident-and-fellow/content/lecture-series.html