Constant Voltage versus Constant Current Deep Brain Stimulation: Is Impedance Fluctuation Sufficient To Favor Constant Current Stimulation?

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Background

- Activa® DBS devices (Medtronic Inc, Minneapolis, MN, USA) deliver electrical stimulation in the constant voltage (CV) mode, but allow switching to a constant current (CC) mode.
- No evidence-based guidelines exist to choose one delivery method over another.
- CC stimulation devices regulate voltage to deliver a programmed current, which may be advantageous initially after DBS implantation, when tissue impedance is known to fluctuate.
- Impedance (R) is also expected to change in response to stimulation strength: V=IR (I – current; V – voltage).
- The extent and clinical significance of impedance changes in vivo over long-term DBS treatment are not well characterized.
- Objectives:
  1) To follow therapy impedance changes over time in patients with CV DBS;
  2) To determine if a correlation exists between changes in therapy impedance and changes in DBS parameters

Methods

- A retrospective chart review (1/2010 – 4/2014) identified Parkinson's disease patients with Activa DBS pulse generators (PC, SC) and 3387 leads programmed in CV mode, with documented therapy impedance over at least 3 consecutive visits after the last DBS-related surgery (initial implant, battery exchange).
- Exclusion criteria:
  - Change in electrode polarity
  - Abnormal impedance (therapy or electrode) reading consistent with possible open or short circuit;
- All impedance values were documented at the beginning of each study visit before making any changes in DBS parameters.
- The magnitude of stimulation was calculated as Charge Density (CD): CD = (Volts / Impedance)*(pulse width) / surface area
  - (surface area is assumed unchanged in the same patients / same electrode configuration) [1].
- Changes of CD and impedance between visits, and compared to baseline (first study visit) were calculated in each patient.

Results

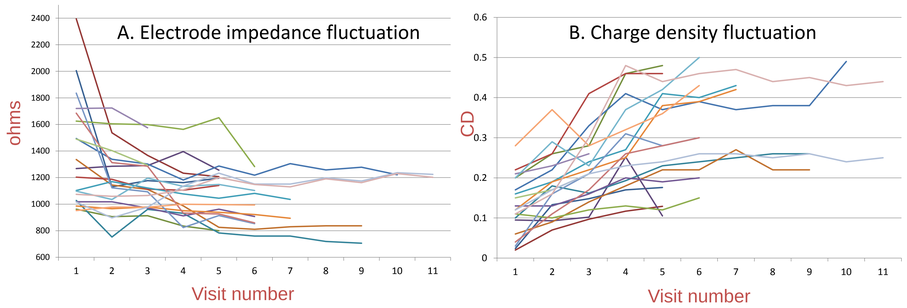
Table 1. Patient and DBS Characteristics

Patients / electrodes, N	10/20
Gender	Male (n=6), Female (n=4)
DBS Device	Activa PC (n=10)
Target	b/l STN (N=4), b/l GPi (N=6)
Mean time to 1st visit with impedance check (days)	158.8 +/-233.1 (all initial DBS implants)
Mean # follow-up visits/electrode	6.55+/-2.3
Mean duration of follow-up/electrode	467.65+/-156.2
Electrode configuration	Bipolar (n=4), double monopolar (n=1), monopolar (n=15)

STN – subthalamic nucleus; GPi – globus pallidus interna

Results, continued

Figure 1. Individual electrode impedance (A) and charge density (B) fluctuation (absolute value) over time



**Each colored line represents an individual electrode.*
Impedance generally varied inversely in relation to CD changes

Figure 2A,B. Correlation between impedance change, CD change and time since surgery

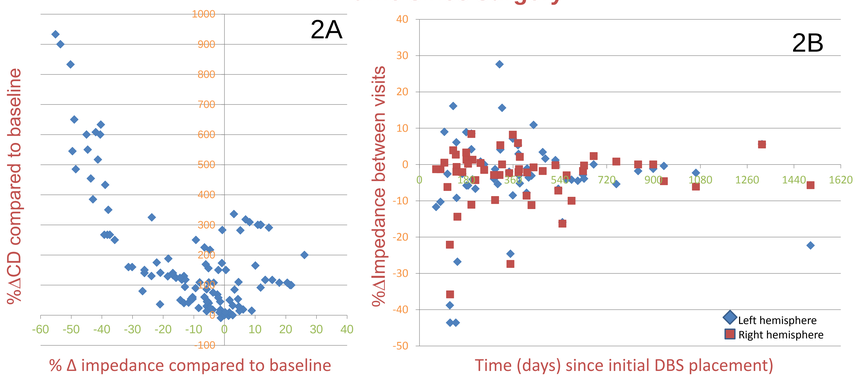


Figure 2A shows change of impedance vs change of CD for all patient-visits (n=111) and all electrodes

Figure 2B shows impedance change between visits vs time since the DBS implantation surgery

Table 2. Impedance change from baseline vs. change between visits

Mean %change impedance from baseline in all electrodes over all visits	-11.04 ±19.37
Mean %change impedance between visits	-3.5 ± 10.7
0-180days	-8.6 ± 16.7
181-360days	-1.1 ± 9.8
>360days	-2.6 ± 5.8

Despite large changes in CD, impedance fluctuations between visits or last visit-vs-baseline were relatively small.

Discussion

- Stimulation current influences Volume of Tissue Activated (VTA) - activated neuronal elements around active contact(s) producing clinical benefits and adverse effects of DBS treatment.
- In CV stimulation, the actual current (I) delivered to brain tissue may vary if there are significant fluctuations of impedance (R) based on the formula: $I = \frac{V}{R}$ (V – voltage)
- In CC stimulation, current does not change but the voltage varies in order to maintain the same current in response to impedance fluctuations.
- A previous study of 63 patients with older Medtonic DBS devices (Kinetra and Soletra) did not identify any significant intra-patient impedance fluctuation over 2 visits with unchanged DBS parameters with CV stimulation devices [2].
- On the other hand, impedance can change significantly during first 3 months after electrode implant due to tissue healing [3]. This observation could theoretically justify the advantages of CC over CV stimulation during the early post-implantation period.
- We analyzed serial impedance readings in response to real-world clinical application of DBS (in the absence of changes in polarity) up to 1504 days after electrode implantation.
- Our findings suggest the following about the degree and nature of impedance changes in chronic DBS therapy:
  - Impedance measurements are generally reduced over time, while CD increases with chronic stimulation.
  - Impedance fluctuations are small relative to changes in CD at any stage of DBS treatment, and vary inversely.
  - Impedance fluctuations are greatest in the initial post-implantation period (<6mos): -8.6% ± 16.7% (range -44 + 16).
  - In the chronic phase of DBS therapy, impedance fluctuations are relatively small, though they may still occur:
    - -1.1% ± 9.8 (range -27 + 28) for 6-12 months
    - -2.6 ± 5.8 (range -22 to +11) for >12 months

Conclusions

- Impedance fluctuations in chronic DBS therapy delivered in CV stimulation mode are minimal over time, and generally decrease, in a real world clinical setting.
- In CV mode, impedance appears to decrease proportionately to increases in CD, as can be expected according to V=IR
- The results of our study do not support the use of CC DBS delivery over CV in order to accommodate for fluctuating impedance in chronic DBS therapy.

References

[1] Marks W. Deep Brain Stimulation Management. Cambridge University Press 2011, New York; p 37.
[2] Sillay KA, Chen JC, Montgomery EB. Long-term measurement of therapeutic electrode impedance in deep brain stimulation. Neuromodulation 10;13:195-200.
[3] Shils JL, Alterman RL, Arle JE. Deep brain stimulation fault testing. In: Deep brain stimulation in neurological and psychiatric disorders. Tarsy et al (Eds) 2008: pp 473-494.