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 – 3/2013) 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
- Impedance values documented at beginning of each study visit, before changes to DBS parameters.
- Magnitude of stimulation was calculated: Charge Density (CD) and Total Electrical Energy Delivered (TEED)

$$CD = \frac{\frac{volts}{impedance} * PW}{surface\ area} \quad [1] \qquad TEED = \frac{voltage^2 * frequency * PW}{impedance} * 1\ second \quad [2]$$

(surface area is assumed unchanged in the same patients / same electrode configuration)

- Changes (Δ) of CD, TEED and impedance between study visits were calculated in each patient.

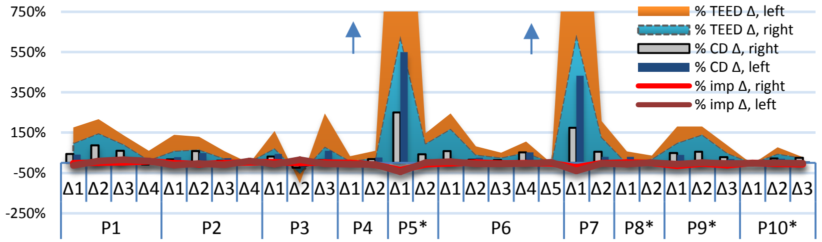
Results

Table 1. Patient and DBS characteristics

Patients / electrodes, N	10 / 20
Gender	Male (N=6), Female (N=4)
Age, yrs: mean + SD (range)	58.5 + 8.8 (42-71)
DBS target	b/l STN (N=4), b/l GPI (N=6)
DBS device	Activa PC (N=10)
First study visit after surgery (initial implant, IPG exchange), days: mean + SD (range)	158 + 243.9 (30-848); all initial implants
Total duration of study follow up, mo: mean + SD (range)	7.15 + 3.68 (4-12.5)
Number of study visits	3 (N=4), 4 (N=3), 5 (N=2), 6 (N=1)
Electrode configuration, N of electrodes	Monopolar (N=15), double monopolar (N=1), bipolar (N=3), double bipolar (N=1)

Results, continued

Figure 1. Between-visit changes (Δ) in impedance, CD and TEED



*Patients are grouped in this figure from the shortest time (P1, 1 month) to the longest time from the DBS implantation to the first study visit (P10, 28.2 months). *patients with STN DBS. All other had GPi DBS.*

Figure 2. Impedance change (Δ) in relation to time from the last DBS-related surgery

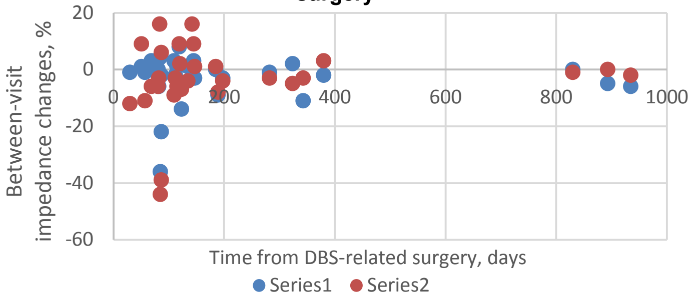


Table 2. Mean Impedance, CD, and TEED changes	mean + SD (range)
Between-visit CD changes, %	46 + 94 (- 24 to 550)
Between-visit TEED changes, %	116 + 273 (- 56 to 1499)
Between-visit Δ therapy impedance, %	- 4 + 11 (- 44 to 16)
Between-visit ΔImpedance in 1st 6mos after implantation, %	-3.6 + 12 (range -44 to 16)
Between-visit ΔImpedance >6mos after implantation, %	-32 + 3.7 (range -11 to 3)

Discussion

- Stimulation current influences Volume of Tissue Activated (VTA): activated neuronal elements around active contact(s) produce 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: $I = \frac{V}{R}$, where V = voltage, R = resistance
  - 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 Medtronic DBS devices (Kinetra and Soletra) did not identify any significant intra-patient impedance fluctuation over 2 visits with unchanged DBS parameters [3].
- On the other hand, impedance can change significantly during first 3 months after electrode implant due to tissue healing [4]. 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 848 days after electrode implantation, with Activa devices.
- Our findings suggest the following about the degree and nature of impedance changes in chronic DBS therapy:
  - Impedance often varied inversely in relation to CD and TEED changes
  - Despite large changes in CD or TEED, impedance fluctuations were relatively small (e.g., Figure 1, see P5 and P7).
  - The largest impedance fluctuations were seen in the initial post-implantation period (<6mos after implantation), likely due to large CD/TEED changes required for DBS optimization.
  - In the chronic phase of DBS therapy (>6mos after implantation), impedance fluctuations are fairly minimal, possibly in the context of relatively small DBS adjustments.
  - Given the inter-patient variability of impedance fluctuations (e.g., P1 vs. P2), it is possible that that other factors contribute to impedance measurements, but the overall fluctuation remains small.

Conclusions

- During active DBS adjustment, intra-patient impedance fluctuations in early DBS therapy in CV mode vary in relation to CD/TEED, though other factors may determine inter-patient variability.
- Impedance fluctuations in chronic DBS therapy in CV mode are minimal.
- The results of our study do not support the use of CC DBS delivery over CV in order to accommodate for fluctuating impedance in the early post-implantation period or in chronic DBS therapy.

References

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