Investigating Changes in Volume of Tissue Activated Across Directional Deep Brain Stimulation Parameters

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Introduction

Directional deep brain stimulation (DBS) enables targeted stimulation of desired brain areas. However, the impact of stimulation amplitude on volume of tissue activated (VTA) for directional and nondirectional (conventional) stimulation is unclear. A computational model was used to evaluate the effect of stimulation parameters on VTA in the subthalamic nucleus (STN).

Methods

A two-stage computational model of STN-DBS was used to analyze neural activation generated with a directional lead (1-3-3-1 configuration).

Finite Element Analysis (FEA) Model

- The first stage involved using a FEA model to calculate electrical potentials generated in the brain with 90 µs cathodic DBS pulses at amplitudes of 1-3 mA.

- The FEA model incorporated a multimodal imaging-based detailed anatomical (MIDA) model of the human head, and the directional DBS lead was placed in the STN with contact 1 at the ventral STN boundary and surrounded by a 0.5 mm thick encapsulation layer (Figures 1, 2a).

Results

- VTA volume increased non-linearly with stimulation amplitude, and was typically largest for one-contact directional stimulation and smallest for non-directional stimulation (Figure 3).

Methods (cont.)

Cellular Models

- The second stage used biophysical cellular models of 5.7 µm diameter myelinated axons [McIntyre 2002] to identify regions of neural activation.

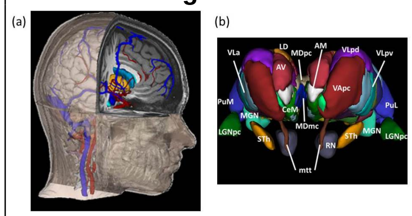
- A total of 6,888 axons were distributed around contact 2, with the axons oriented perpendicular to the lead axis (Figure 2b).

- FEA electrical potentials were interpolated along each axon, and delivered as extracellular stimulation to determine the VTA [Butson 2008] for:

- One-contact directional DBS (segment 2B)
- Two-contact directional DBS (2A-B)
- Non-directional DBS (2A-C)

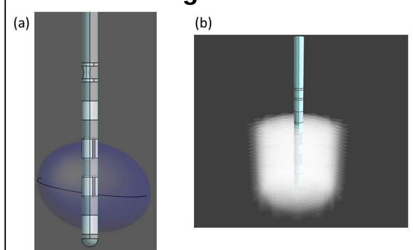
- The extent of directionality was calculated as the percentage of VTA volume on the side of the lead with segment 2B.

Figure 1



(a) Structures in the MIDA head model. (b) Thalamus and surrounding nuclei within the MIDA model. Image from [Iacono 2015].

Figure 2



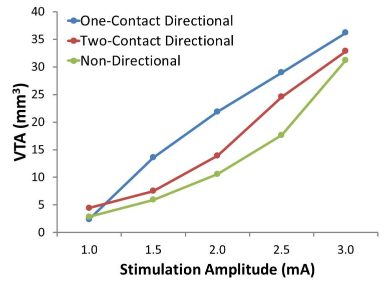
(a) FEA model representation of the DBS electrode within the STN. (b) Locations of the modeled axons.

Results (Continued)

- Directional stimulation but not non-directional stimulation allowed for spatial steering of the VTA (Figure 4).

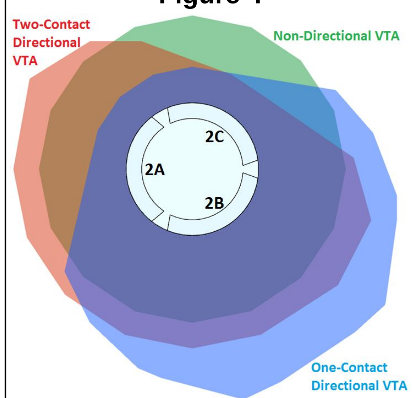
- The extent of directionality was higher for one-contact directional DBS (0.5mA: 94.5%, 3mA: 80.4%) than two-contact directional DBS (range: 57.7-59.8%) and non-directional DBS (49.8-51.7%).

Figure 3



VTA volume for directional and non-directional DBS across stimulation amplitudes.

Figure 4



Cross-sectional view of VTAs for directional and non-directional DBS at 2 mA.

Conclusions

A model of STN-DBS demonstrated that VTA volume varies non-linearly with stimulation amplitude, and that the VTA is larger with directional stimulation than non-directional stimulation.

In addition, directional DBS allows for spatial steering of the VTA, and the extent of directionality increased with lower stimulation amplitudes.

Learning Objectives

1.Describe how directional DBS generates a targeted stimulation field.
2.Discuss how changes in stimulation parameters impact the size and shape of the VTA.
3.Understand the basis of computational modeling for investigating DBS.

Acknowledgements

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References

Butson CC and McIntyre CC. Current steering to control the volume of tissue activated during deep brain stimulation. Brain Stimul 2008 Jan;1(1): 7-15.

Iacono MI, et al. MIDA: a multimodal imaging based detailed anatomical model of the human head and neck. PLOS One Apr 2015;10(4): e0124126.

McIntyre CC, Richardson AG, Grill WM. Modeling the excitability of mammalian nerve fibers: influence of afterpotentials on the recovery cycle. J Neurophysiol 2002 Feb;87(2): 995–1006.