

Bio-heat Model of Kilohertz-frequency Deep Brain Stimulation Increases Brain Tissue Temperature

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Niranjan Khadka^{1*}, Irene Harmsen², Andres Lozano², Marom Bikson¹

¹The City College of New York, Department of Biomedical Engineering, New York, USA

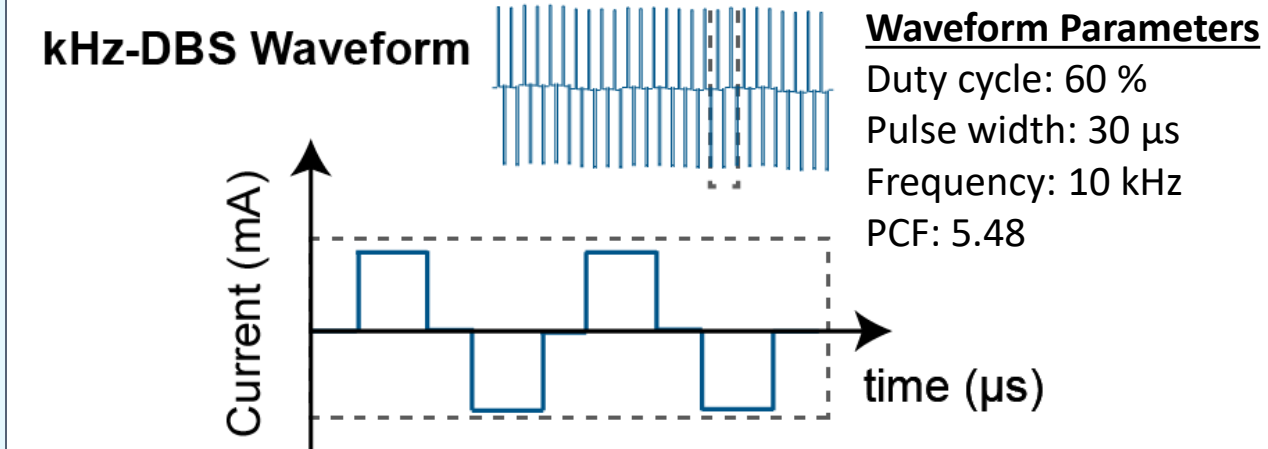
²University of Toronto, Department of Surgery, Toronto Western Hospital, Canada

The City College of New York

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Introduction

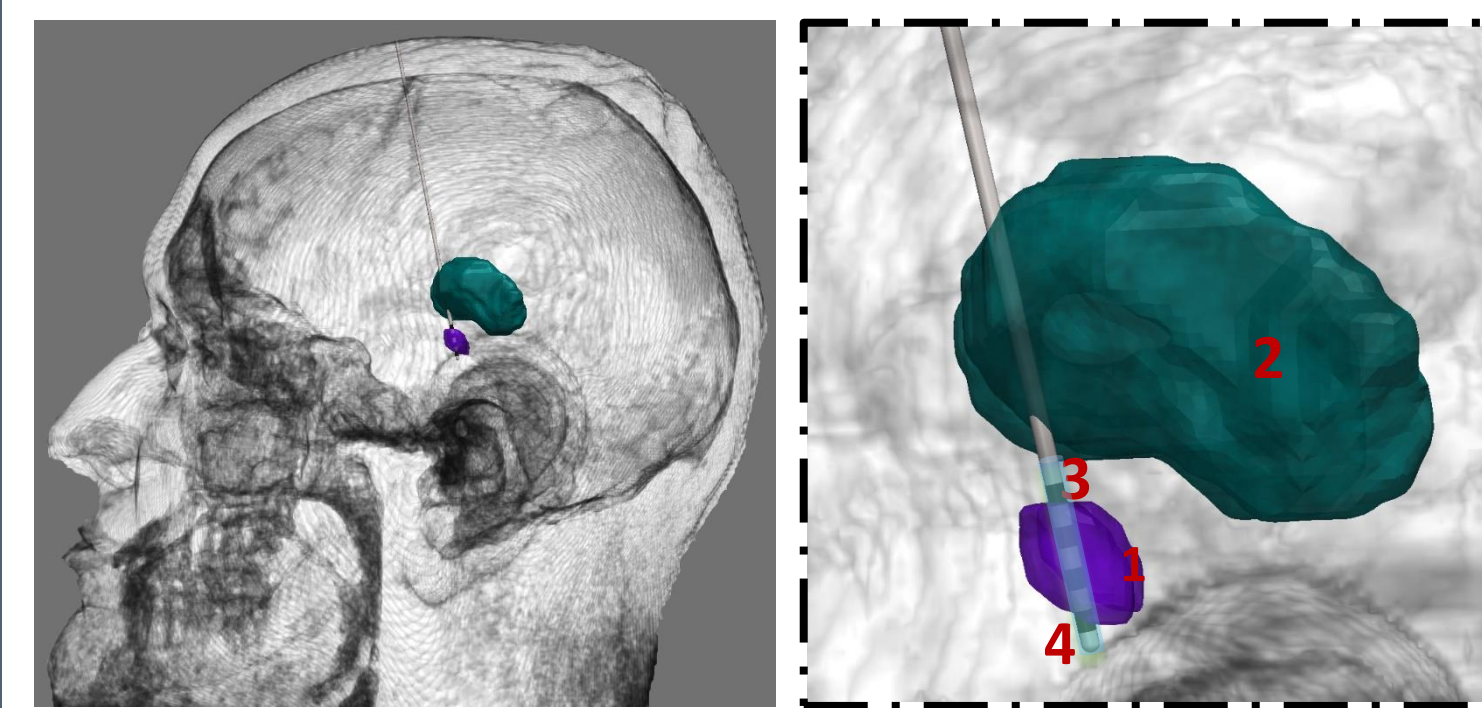


- Early clinical trials suggest that DBS at kHz-frequencies may be effective in improving motor symptoms. (Harmsen et al., 2019)
- 10 kHz-DBS can deliver more power in tissue compared to conventional frequency DBS, reflecting increased pulse compression (PCF; duty cycle) and thus tissue heating.
- **Hypothesis:** kHz-DBS modulates neuronal function via moderate tissue heating, analogous to kHz-SCS. (Zannou L, Khadka N et al., 2019a*, 2019b)
- **Objective:** To predict the role of tissue heating in kHz-DBS by characterizing the range of temperature changes during clinical kHz-DBS protocols.

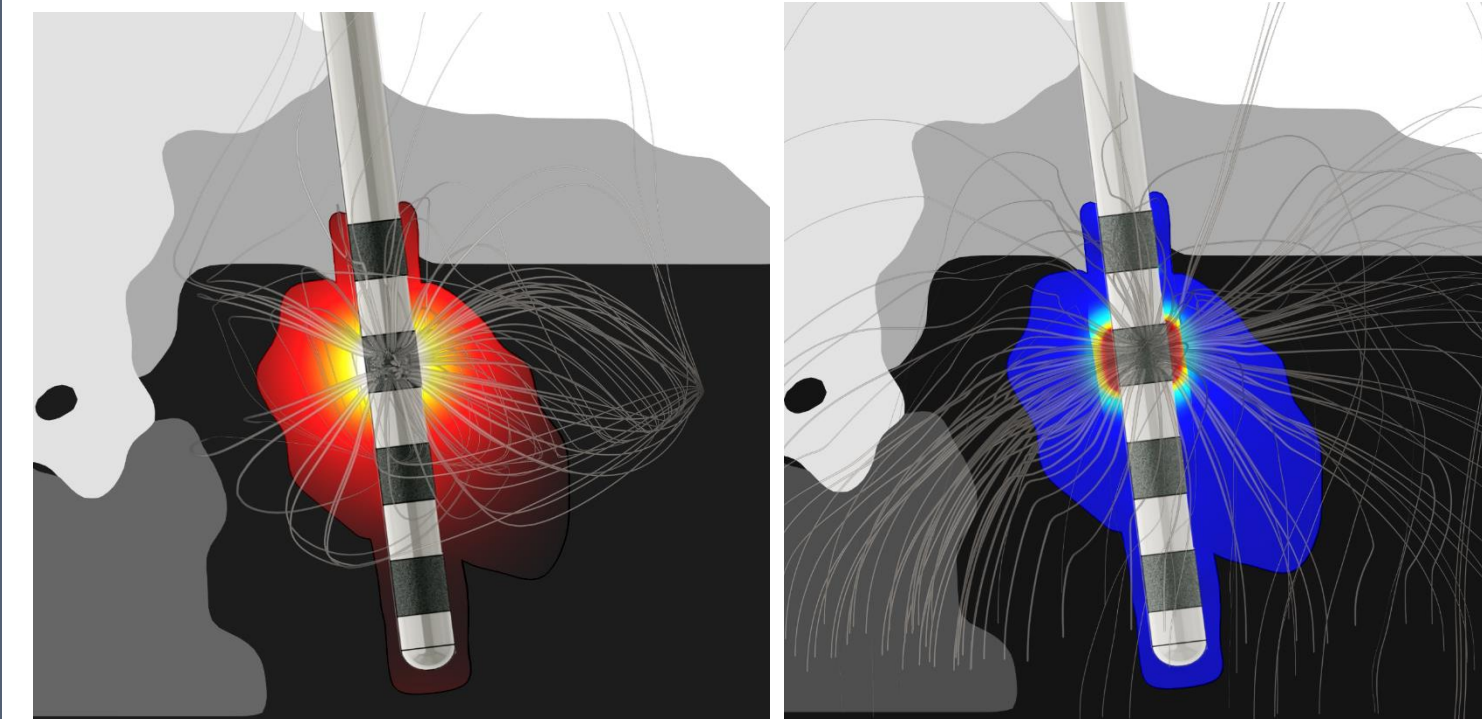
Methods

- Developed a high-resolution MRI-derived DBS head model of Joule-heat coupled bio-heat to establish the role of tissue heating.
- Model solved using stimulation coupled Pennes' bioheat transfer equation.
- DBS lead positioned at the STN and surrounded by encapsulation layer.
- Simulated monopolar and bipolar electrode montages.
- **Volume of Tissue Activated (VTA) or Heated (VTH) contrasted.**

Results



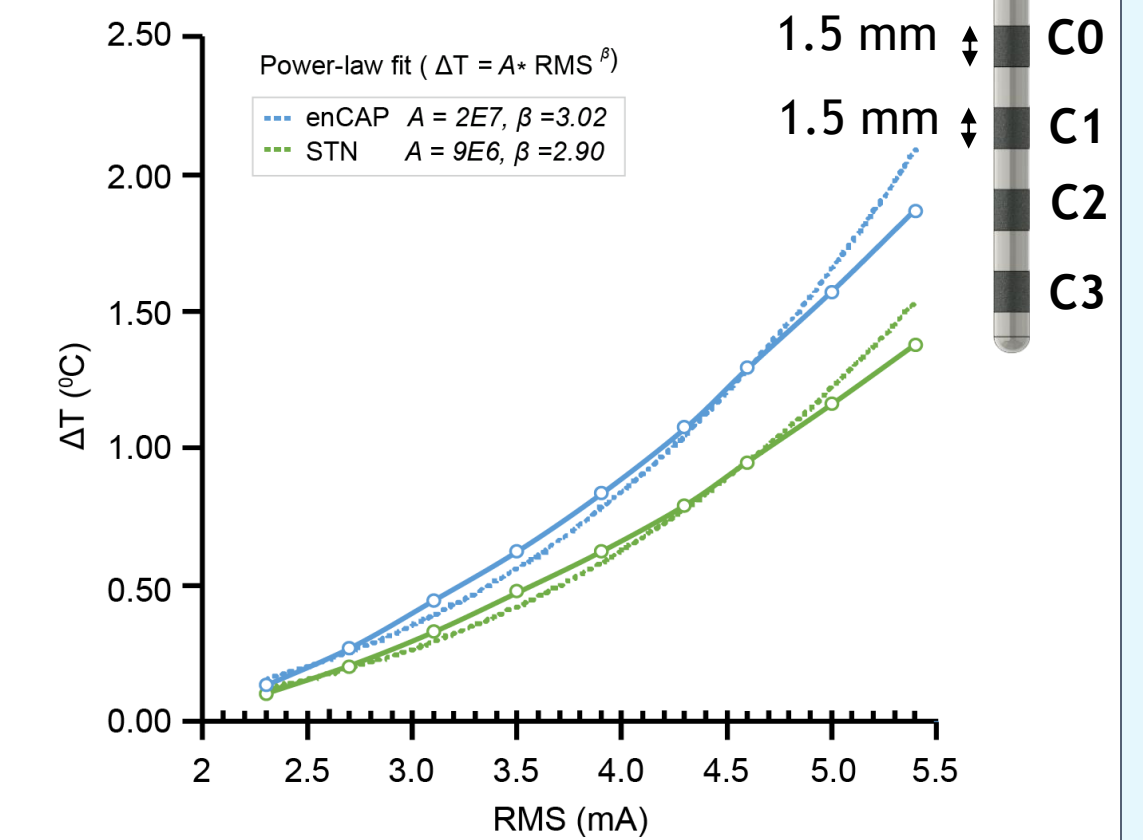
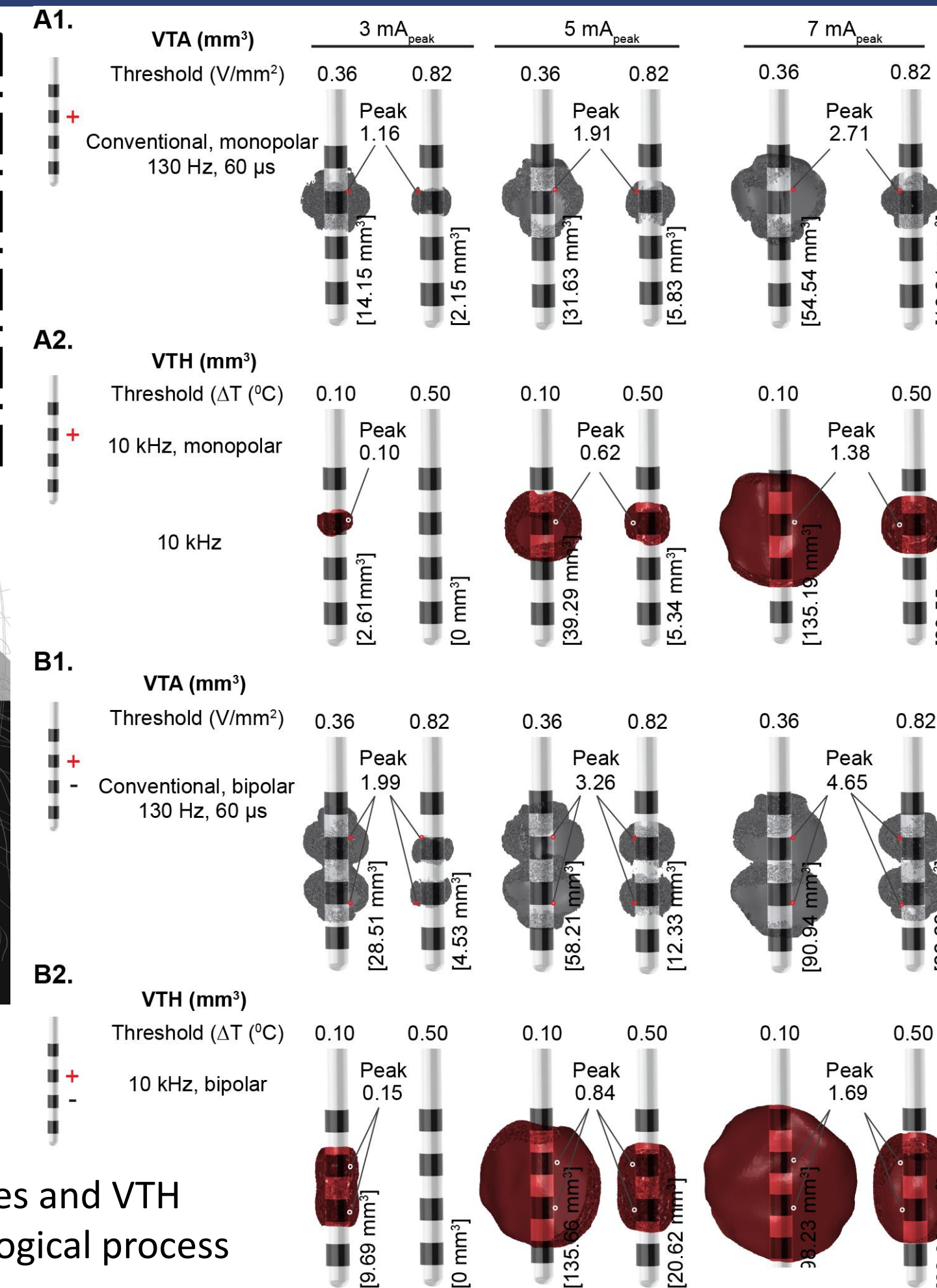
1: Subthalamic nucleus; 2: Thalamus; 3: DBS lead; 4: Encapsulation



- VTA analysis addresses fiber activation of various types and VTH analysis will depend on yet-unspecified neurophysiological process predicted by temperature threshold.
- Under assumption simulated here, the VTA and VTH are comparable (roughly double for bipolar vs monopolar) for the same dose suggesting that stimulation and heating have some additive effects in neural activation (neuromodulation).

Conclusion

- While the specific mechanisms of heating-based neuromodulation remains to be shown, there is a long record of neuromodulation techniques associated with tissue heating and reversible change in brain excitability.
- Subject to validation with *in vivo* measurement, neuromodulation through a heating mechanism of action by kHz-DBS can indicate multiple novel therapeutic pathways and strategies for dose optimization.



- VTH, VTA, and peak heating increases supra-linearly with stimulation intensity (power law fit)
- Clinical intensity (3-7 mA_{peak}) produces 0.10-1.38 °C heating at the STN under standard conductivities.
- Max. temperature increases are predicted inside the enCAP producing 0.13-1.87 °C.

References

- Zannou AL*, Khadka N*, Truong DQ, et al. *Temperature increases by kilohertz frequency spinal cord stimulation*. Brain Stimul. 2019;12(1):62-72.
- Zannou AL, Khadka N, FallahRad M, Truong DQ, Kopell BH, Bikson M. *Tissue Temperature Increases by a 10 kHz Spinal Cord Stimulation System: Phantom and Bioheat Model*. Neuromodulation. 2019

Contact: bikson@ccny.cuny.edu
nkhadka@ccny.cuny.edu



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