Temperature Increases by High-Rate Spinal Cord Stimulation

Looking for mechanisms of action for kHz therapies

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What is high-rate stimulation and why does it require “new” mechanisms?

• Emerging neuromodulation technologies apply stimulation at high-rates (1-10 kHz) that are higher than conventional techniques (~100 Hz)

• High rate stimulation also means short pulse durations (e.g. at 10 kHz: 40 µS)

• Because of the low-pass properties of neuron membranes, high-rate stimulation is “not effective”

• **Amount of heat deposited in tissue can increase at high-rate as duty cycle increases** (“pulse compression”)

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![Graph showing pulse duration and frequency](image-url)
Temperature mapping around SCS lead in phantom

- Amount of heat deposited in tissue independent of sinusoidal frequency, sensitive to environment
Temperature increase tracks RMS. Therefore: Increases at high-rates compared to conventional waveforms.
SCS Bio-Heat Model architecture

- 8 compartment types (CAD), plus 2 physical SCS lead
- Each compartment: electrical conductivity and thermal conductivity
- Some compartments with blood perfusion and matched metabolism
- FEM: ~5m elements, adaptive mesh
- Steady state solutions
Current and heat model

- Distinct E-fields and Temperature changes in tissue predicted
SCS temp ruse predictions: Sensitivity to parameters

- >600 model parameter permutations
- The spinal column in an enclosed environment wrapped in insulator
- With SCS a chronic source of heat addition
Temperature Increases by High-Rate Spinal Cord Stimulation

• High-Rate (kHz) spinal cord stimulation (SCS) deposits significantly more power in tissue compared to conventional SCS frequencies, reflecting increased duty cycle ("pulse compression")

• An experimentally verified bio-heat model shows SCS waveform power determines (RMS) joule tissue heating and predicts temperature increases

• ~0.5 °C during clinical relevant High-Rate (kHz) parameters

• Did not model metabolic or other dynamic tissue response to SCS

• Does not exclude other mechanisms but would be adjunct to them (e.g. temperature should not be ignored in any case)

• Tissue heating by kHZ-SCS may impact short and long-term outcomes
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Slides and References at NeuralEngr.com