The Activating Function Based Volume of Tissue Activated (VTA): An Axon Orientation and Projection Independent Method For Predicting Neural Activation by Deep Brain Stimulation (DBS)

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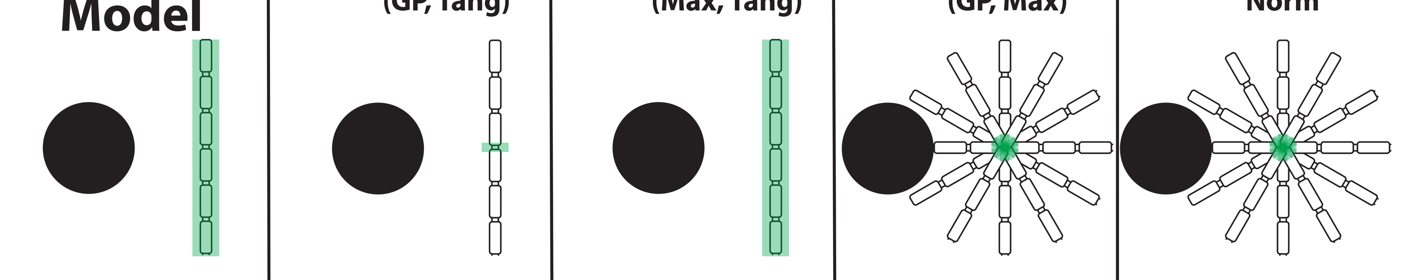
Introduction:

Computational models of the volume of tissue activated (VTA) are commonly used both clinically and for research. Because of the computational demands of the traditional axon model approach, alternative approaches to approximate the VTA have been developed. **The goal of this study is to evaluate multiple approaches of calculating approximations of the VTA for monopolar and bipolar stimulation on cylindrical and directional lead designs**.

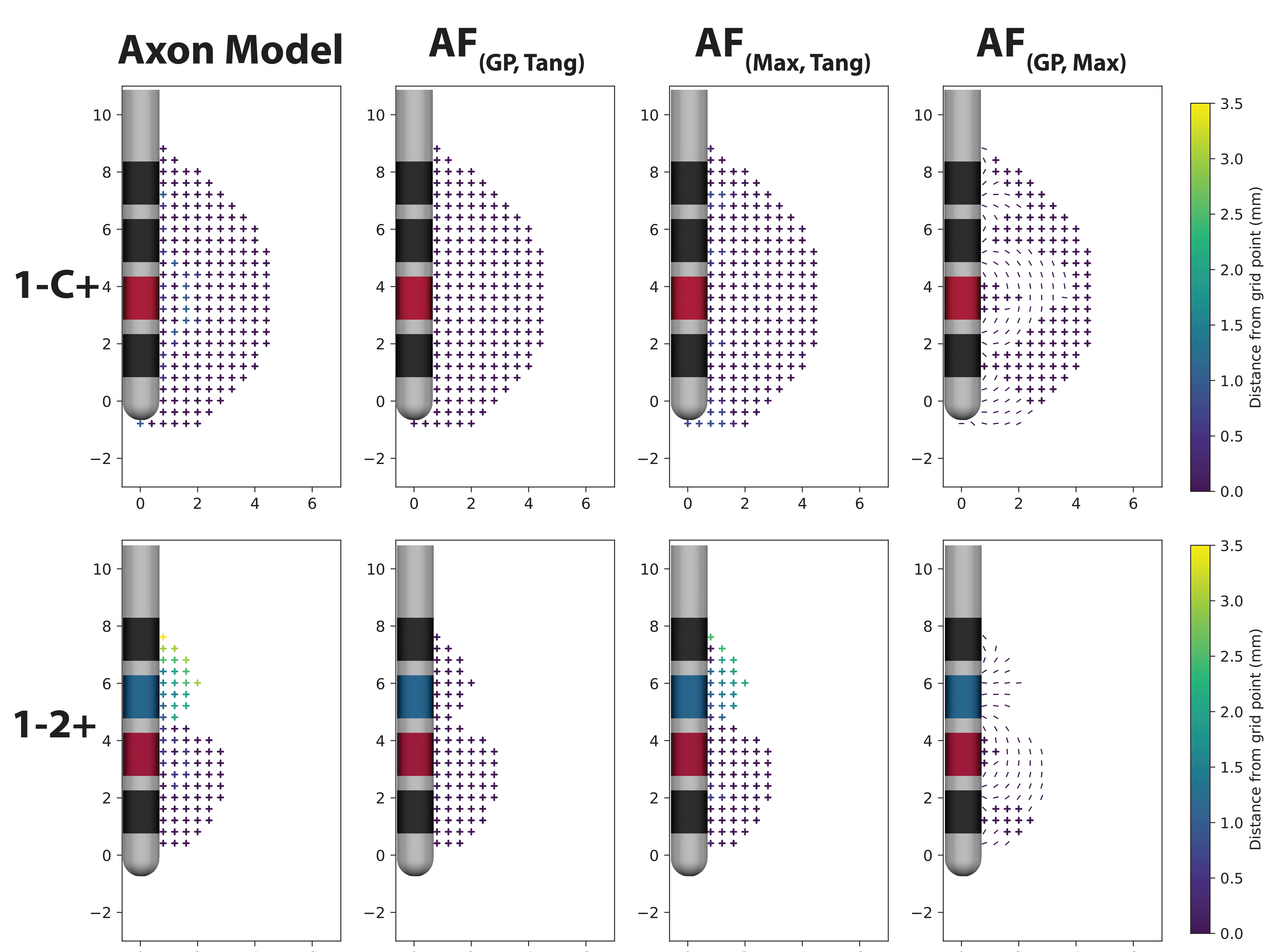
Methods:

We used a finite element method approach to simulate the evoked potential distributions from DBS. We used the calculated potentials to model a McIntyre, Richardson, Grill axon, calculate the Hessian matrix, and calculate the norm of the electric field at each point in our discrete representation of tissue surrounding each electrode. We used the results of the models to establish activation threshold values for the activating function and electric field norms, and evaluate the resulting VTA from five different calculation methods.

Summary of VTA Calculation Methods

	Axon Model	$AF_{(GP, Tang)}$	$AF_{(Max, Tang)}$	$AF_{(GP, Max)}$	EF_{Norm}
Method Visualization					
Data Value	Axon Model Simulation	Activating Function	Activating Function	Activating Function	Electric Field Norm
Data Orientation	Tangential	Tangential	Tangential	Maximum Eigenvector	Norm of Electric Field Gradient
Data Origin	Action Potential Initiation Site	Grid Point	Maximum Value Along Axon	Grid Point	Grid Point

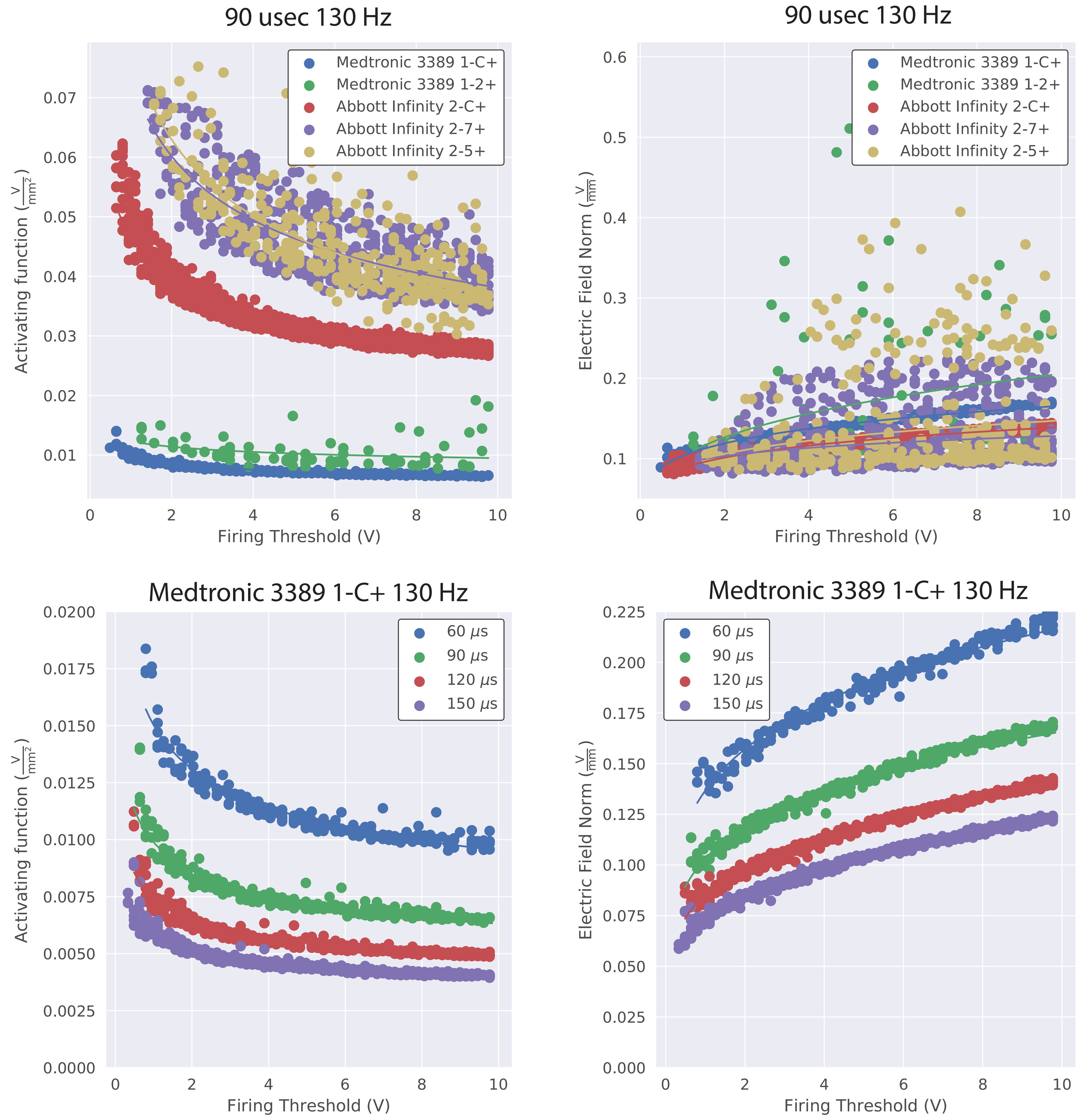
Comparison of Method Data Orientation and Location



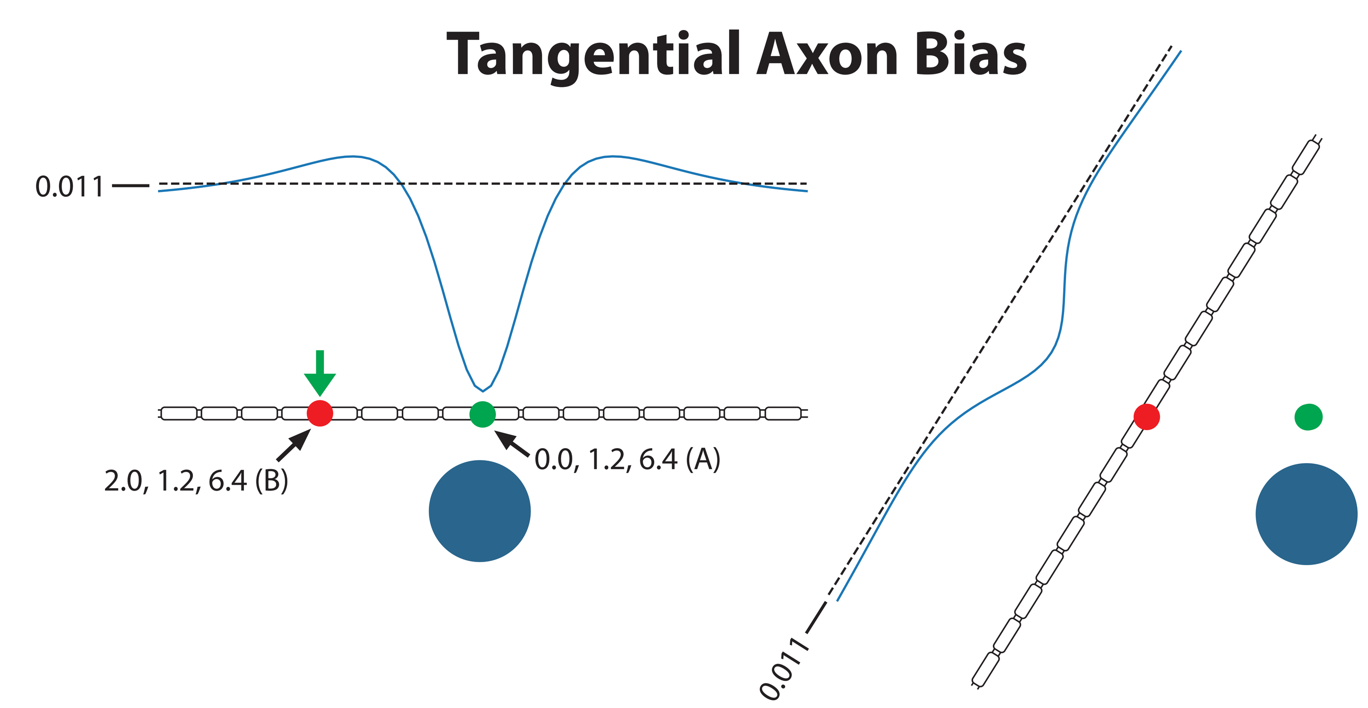
Results:

Activating function and electric field norm threshold values were dependent on stimulation amplitude, electrode configuration, and pulse width. All methods resulted in highly similar approximations of the VTA for monopolar stimulation for both the directional the cylindrical DBS lead designs. For bipolar stimulation, the axon model method and $AF_{(Max, Tang)}$ produced similar approximations of the VTA. For bipolar stimulation $AF_{(GP, Max)}$ produced a approximation of the VTA that was larger than any of the other methods. $AF_{(GP, Max)}$ is not biased by only using tangentially oriented axons, unlike the axon model method and $AF_{(Max, Tang)}$.

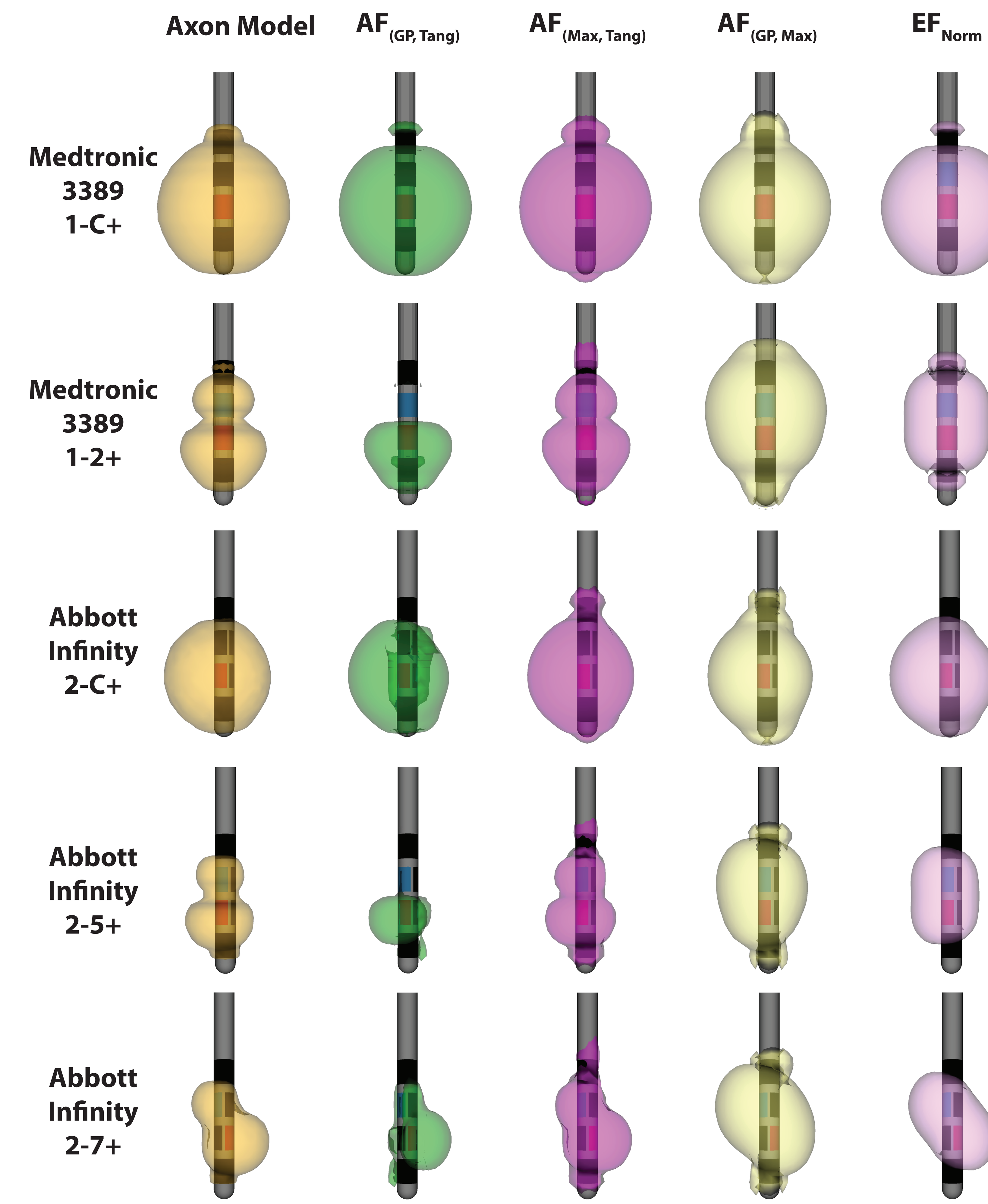
Activation Threshold Values



Tangential Axon Bias



VTA Surfaces



Discussion/Conclusions:

- Activating function and electric field norm threshold values are electrode configuration, stimulation amplitude, and stimulation pulse width specific.
- For monopolar stimulation, all methods produce highly similar approximations of the VTA.
- For bipolar stimulation, $AF_{(Max, Tang)}$ is the only method that produces an approximation of the VTA that is similar to the axon model method.
- Axon model method and $AF_{(Max, Tang)}$ are biased by only using tangentially oriented fibers.
- $AF_{(GP, Max)}$ can be used to calculate the VTA in a way that does not assume tangential fiber orientation.

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