Simulation Study for Estimating Effective Resistivity in Heterogenenous Neural Tissues

Kyle Loizos*, Anil Kumar RamRakhyani, and Gianluca Lazzi
The University of Utah, Salt Lake City, UT, USA

Electromagnetic numerical methods, such as the finite element method (FEM), admittance method (AM), or finite-difference time-domain (FDTD), often use models that are discretized based on the dielectric properties of included materials. When studying neural tissue, the values typically originate from measurements taken across bulk tissue. These are then used to describe the materials in the model as lumped circuital elements, converting each voxel into a homogeneous resistance. While this approach can provide a good estimate of the resistance of the tissue at macro-scales, it may be questionable when voxel resolutions down to 1-5 um are considered. At these voxel resolutions, each voxel may contain different sections of cell bodies, axons, dendritic regions, etc., each having different resistive properties. There is an inherent heterogeneity that is disregarded in previous homogeneous model approximations.

In this work, a simulation study is conducted in order to estimate the effective resistivity in various layers in the retina, based on the properties of the dense cellular networks it contains. Small sections of retina are considered at a time, with models built spanning hundreds of micrometers with a resolution as fine as nanometers. The models are populated with voxelized cellular morphologies: these are then discretized based on measured resistivity of the intracellular space, membrane, and extracellular space of each individual cell type, as well as the resistances of gap junctions and synaptic mechanisms present in the considered space. The morphology and synaptic information is based on cell tracings and connectomics data from annotated transmission electron microscopy (TEM) images. Admittance method simulations are then run, applying a current across each volume and solving for the voltage. Given the current and voltage, the resistance of the tissue can be solved for using Ohm's Law. This can then be repeated in different directions, allowing for the anisotropic effective resistivity of sections of retina to be estimated.

The overall goal is to create an accurate set of conductance values for the use in a multi-scale retinal model for simulating retinal prostheses, which include bulk tissue and electronics as well as cellular networks. This would allow for the bulk tissue to be described with properties matching the cellular network models. Results will include the estimated effective resistivity of different sections of retina, comparisons with measurements, and example applications in models of retinal prosthetics.