Computational Modeling of Current Flow in the Bipolar Cell Pathways of Degenerated Retina

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Retinal bipolar cells play a significant role in the visual signal processing through retinal layers. The bipolar cells collect postsynaptic output from the outermost layer of photoreceptors and transfers processed information to the innermost layer of ganglion cells. Retinal degenerative diseases, such as retinitis pigmentosa and age-related macular degeneration, start with damage to photoreceptors. The absence of input from photoreceptors leads to functional alterations and extensive remodeling of remaining cells. For example, unusual long branches grow in dendrites and axons of degenerated bipolar cells. Further, rod and cone bipolar cells make abnormal synaptic connections with remaining cone and rod photoreceptors, receptively [B. W. Jones et al., Journal of Ophthalmology, 2013].

Retinal prosthetic devices stimulate the surviving retinal cells by applying external current using implanted electrodes. Although these devices restore partial vision, the quality of restored vision is limited. To improve the performance of retinal prostheses, further knowledge about degenerated retina and changes with the progression of the disease is essential. Computational modeling of retinal cells and networks can be helpful in widening the current understanding of retina. Moreover, computational models can be used to predict the response to different stimulus waveforms and electrode designs [K. Loizos et al., IEEE TNSRE, 2018]. Models of retinal pathways focused on bipolar cells can be particularly useful in guiding experiments on subretinal implants, in which electrodes are mounted inside the middle layer of the retina, and bipolar cells are stimulated electrically.

In this work, the computational models for retinal bipolar cell pathways in the degenerated retina are developed. Realistic cell morphologies and synaptic connections of the network are implemented using connectome datasets, constructed using TEM images of an early stage degenerated rabbit retina. The passive membrane and active ion currents of each cell are implemented by conductance-based models. The light stimulus and transduction of light at photoreceptors is represented by a mathematical model of photocurrent injection to photoreceptors. The models are implemented in Neuron simulation environment. The results will provide a comparison between current flow in healthy and degenerated retinal cell pathways, with the focus on bipolar cells.