ION TRANSPORT MODELING
FOR RETINAL ROD PHOTORECEPTOR CELLS

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ABSTRACT

In this study, a mathematical model is developed to describe the ion transport activities associated with the response of rod photoreceptor to light stimulus. In the model, the cell body is modeled as two capacitors connected via the connecting cilium. Roles of different ion channels during a photoreceptor light response are analyzed, and the relations between changes in ion concentration and response currents are assessed. Methods are developed for computing the membrane potential from ion concentrations and relating the material and electrical resistances. The steady state under different conditions can be uniquely defined with only three measured values.

The model can effectively describe the rod photoreceptor response to different light stimuli. Model simulation of the a-wave for progressive narrowing of the connecting cilium corresponds well with published literature on hereditary retinal degeneration of Abyssinian cats. Reductions in amplitude and changes in the a-wave waveform are observed in different stages of the disease. Changes in the receptor response amplitude may not be measurable till the conductance of the connecting cilium is reduced to a comparable magnitude of the ion channels. The model can provide quantitative information of ionic activities, changes in ion concentrations and membrane voltage in the outer segment and the inner compartment. The ionic environment is found to be different between the outer segment and the inner compartment. During receptor response, changes in the outer segment appear to be stronger and quicker than those in the inner compartment. Reductions in the connecting cilium transport can reset the dark resting state.