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Modeling the Electrophysiology of Jellyfish Using the FitzHugh-Nagumo Equations

Jellyfish are among the simplest animals that possess a true nervous system. The primitive jellyfish nervous system is called a nerve net. Nerve nets are involved in the control of muscles, which are used for pumping water. Pumping water serves a number of purposes, such as swimming, feeding, and decelerating during descent.

The nerve nets of jellyfish synapse with pacemaker structures. Pacemakers are capable of depolarizing without receiving an external stimulus. These pacemakers set the pulsing rhythm for muscle contractions. Jellyfish seldom remain at a constant pulsing frequency; changes in the frequency can be erratic for a single specimen. Frequency also tends to vary by size as large jellyfish tend to pump slower than small jellyfish.

The dynamics of the nerve net neurons can be modeled by the FitzHugh-Nagumo equations. The FitzHugh-Nagumo equations are a simplification of the Hodgkin-Huxley model for nerve impulses. By incorporating a diffusion term, action potentials can be shown to spread in two-dimensional space. There are two main types of nerve nets found in jellyfish: the motor nerve net and the diffuse nerve net. The motor nerve net can be conceived as an annulus in two-dimensional space. A single signal can spread bi-directionally around the ring until it cancels itself at the halfway point. The diffuse nerve net can be represented by a circle. Signals on the diffuse nerve net will spread isotropically until reaching the boundaries. The motor and diffuse nerve nets both interface with pacemakers. Information from both nerve nets is thought to influence the depolarization of pacemakers.

This model demonstrates many of the features and phenomena observed in the electrophysiology of jellyfish. It can be shown that high-frequency pacemakers tend to dominate over slower pacemakers. This model can exhibit the fast conducting action potentials of the motor nerve net as well as the slow conducting action potentials of the diffuse nerve net.