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Mathematical model of subthalamic nucleus neuron - characteristic activity patterns and bifurcation analysis

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Mathematical model of subthalamic nucleus neuron - characteristic activity patterns and bifurcation analysis

The subthalamic nucleus (STN) has an important role in the pathophysiology of the basal ganglia in Parkinson's disease. The ability of STN cells to generate bursting rhythms under either transient or sustained hyperpolarization may underlie the excessively synchronous beta rhythms observed in Parkinson's disease. In this study, we developed a conductance-based single compartment model of an STN neuron, which is able to generate characteristic activity patterns observed in experiments including hyperpolarization-induced bursts and post-inhibitory rebound bursts. This study focused on the role of three currents in rhythm generation: T-type calcium (CaT) current, L-type calcium (CaL) current, and hyperpolarization-activated cyclic nucleotide-gated (HCN) current. To investigate the effects of these currents in rhythm generation, we performed a bifurcation analysis using slow variables in these currents. Bifurcation analysis showed that the HCN current promotes single-spike activity patterns rather than bursting in agreement with experimental results. It also showed that the CaT current is necessary for characteristic bursting activity patterns. In particular, the CaT current enables STN neurons to generate these activity patterns under hyperpolarizing stimuli. The CaL current enriches and reinforces these characteristic activity patterns. In hyperpolarization-induced bursts or post-inhibitory rebound bursts, the CaL current allows STN neurons to generate long bursting patterns. Thus, bifurcation analysis explained the synergistic interaction of the CaT and CaL currents, which enables STN neurons to respond to hyperpolarizing stimuli in a salient way. The results of this study implicate the importance of CaT and CaL currents in the pathophysiology of the basal ganglia in Parkinson's disease.