Complex Dynamics in a Morphologically Heterogeneous Biological Medium

Authors : Turky Al-Qahtani, Roustem Miftahof

Abstract : Introduction: Under common assumptions of excitabi-lity, morphological (cellular) homogeneity, and spatial structural anomalies added as required, it has been shown that biological systems are able to display travelling wave dynamics. Being not self-sustainable, existence depends on the electrophysiological state of transmembrane ion channels and it requires an extrinsic/intrinsic periodic source. However, organs in the body are highly multicellular, heterogeneous, and their functionality is the outcome of electro-mechanical conjugation, rather than excitability only. Thus, peristalsis in the gut relies on spatiotemporal myoelectrical pattern formations between the mechanical, represented by smooth muscle cells (SM), and the control, comprised of a chain of primary sensory and motor neurones, components. Synaptically linked through the afferent and efferent pathways, they form a functional unit (FU) of the gut. Aims: These are: i) to study numerically the complex dynamics, and ii) to investigate the possibility of self-sustained myoelectrical activity in the FU. Methods: The FU recreates the following sequence of physiological events: deformation of mechanoreceptors of located in SM; generation and propagation of electrical waves of depolarisation - spikes - along the axon to the soma of the primary neurone; discharge of the primary neurone and spike propagation towards the motor neurone; burst of the motor neurone and transduction of spikes to SM, subsequently producing forces of contraction. These are governed by a system of nonlinear partial and ordinary differential equations being a modified version of the Hodgkin-Huxley model and SM fibre mechanics. In numerical experiments; the source of excitation is mechanical stretches of SM at a fixed amplitude and variable frequencies. Results: Low frequency ($0.5 < v < 2$ Hz) stimuli cause the propagation of spikes in the neuronal chain and, finally, the generation of active forces by SM. However, induced contractions are not sufficient to initiate travelling wave dynamics in the control system. At frequencies, $2 < v < 4$ Hz, multiple low amplitude and short-lasting contractions are observed in SM after the termination of stretching. For frequencies ($0.5 < v < 4$ Hz), primary and sensory neurones demonstrate strong connectivity and coherent electrical activity. Significant qualitative and quantitative changes in dynamics of myoelectical patterns with a transition to a self-organised mode are recorded with the high degree of stretches at $v = 4.5$ Hz. Increased rates of deformation lead to the production of high amplitude signals at the mechanoreceptors with subsequent self-sustained excitation within the neuronal chain. Remarkably, the connection between neurones weakens resulting in incoherent firing. Further increase in a frequency of stimulation ($v > 4.5$ Hz) has a detrimental effect on the system. The mechanical and control systems become disconnected and exhibit uncoordinated electromechanical activity. Conclusion: To our knowledge, the existence of periodic activity in a multicellular, functionally heterogeneous biological system with mechano-electrical dynamics, such as the FU, has been demonstrated for the first time. These findings support the notion of possible peristalsis in the gut even in the absence of intrinsic sources - pacemaker cells. Results could be implicated in the pathogenesis of intestinal dysrythmia, a medical condition associated with motor dysfunction.

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