Fibrosis-Induced Arrhythmias: A Computational Approach to Micro-Reentries and Ectopic Foci

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Cardiac tissue is a prime example of a heterogeneous excitable system. Fibrosis is known to promote various types of cardiac arrhythmias by disrupting the normal propagation of electrical stimuli. In fibrotic tissue, conduction becomes more erratic and fragmented, leading to a noisy, breakable propagation pattern. The electrical wave follows a zigzag trajectory through a maze of non-conducting fibrotic regions.

We model cardiac tissue as a discrete system, incorporating random disconnections between cells to simulate the progressive growth of fibrosis. Monte Carlo simulations are then performed to determine the levels of fibrosis and ischemia at which the infarct region is most likely to behave as an ectopic focus. Our results reveal the emergence of micro-reentry and ectopic activity within micro-fibrotic regions, particularly near a critical topological threshold known as the percolation threshold. Using a simplified tissue model, we numerically compute electrocardiograms (ECGs) that successfully replicate experimental complex fractional atrial electrograms (CFAEs).

We apply such methodology to Patient-specific geometrical models of the ventricles, as well as infarct and peri-infarct zones generated from MRI images. Electrophysiological behavior is simulated using a human ventricular myocyte model [1]. We assess the minimal size of three-dimensional tissue slabs capable of sustaining micro-reentries under different stimulation protocols [2].

Our findings highlight the importance of the discrete topology of cardiac tissue. Notably, the proximity of the fibrosis fraction to the percolation threshold appears to be a key determinant in the formation of micro-reentries and the onset of certain arrhythmias.

[1] R. Sachetto, S. Alonso, F. Otaviano Campos, B. M. Rocha, J. F. Fernandes, T. Kuehne, R. W. Dos Santos. Ectopic beats arise from micro-reentries near infarct regions in simulations of a patient-specific heart model. *Scientific reports* **8** (2018), 16392.

[2] R. Sachetto, S. Alonso, R. W. Dos Santos. Killing many birds with two stones: hypoxia and fibrosis can generate ectopic beats in a human ventricular model. *Frontiers in Physiology* **9** (2018), 764.