Pis'ma v ZhETF, vol. 106, iss. 9, pp. 585 – 586

Success of spiral wave unpinning from the heterogeneity in a cardiac tissue depends on its boundary conditions

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Submitted 8 September 2017
Resubmitted 25 September 2017

DOI: 10.7868/S0370274X17210111

Efficient heart functioning as a pump is regulated by excitation waves, and disorder in their propagation may lead to arrhythmias, often lethal ones [1]. One of the main causes of the potentially lethal tachyarrhythmias is a reentry, or rotating wave, which may arise due to the interaction of propagating excitation waves with specific anatomical features, such as scars from infarcts, or due to the asymmetrical passing of the excitation through the narrow pathways [2]. In order to avoid the damaging effect of the high voltage shock, so called low-voltage defibrillation have been extensively developed during last two decades [3, 4]. The mechanism of the low voltage defibrillation is based on the interaction between two activity sources. It is known that the high-frequency stimuli induce drift of the spiral wave and its further collision with the boundary of an excitable tissue [5]. However, to destabilize the rotating wave, pinned to the heterogeneity and induce its drift it is first necessary to detach or unpin the wave from the stabilizing obstacle [6].

In a present work, we study conditions of unpinning of spiral wave anchored to the defect by the wave train with a fixed frequency of stimuli by posing the main accent on the boundary conditions of this defect. In the previous studies, as a rule, no-flux boundary conditions were applied [7].

Commonly, it was assumed, that the borders caused by traumas or disease, e.g. scars after ischemia, have no leakage of ion currents from the excitable tissue to the traumatized one [8]. However, this assumption lacks evidence.

In this work, we studied the problem of reentry elimination and unpinning from the obstacles with varying boundary conditions. The computer simulations were performed using Korhonen detailed model [9, 10] for neonatal rat ventricular cardiomyocytes (NRVM), and as a basic experimental model we choose the cultured

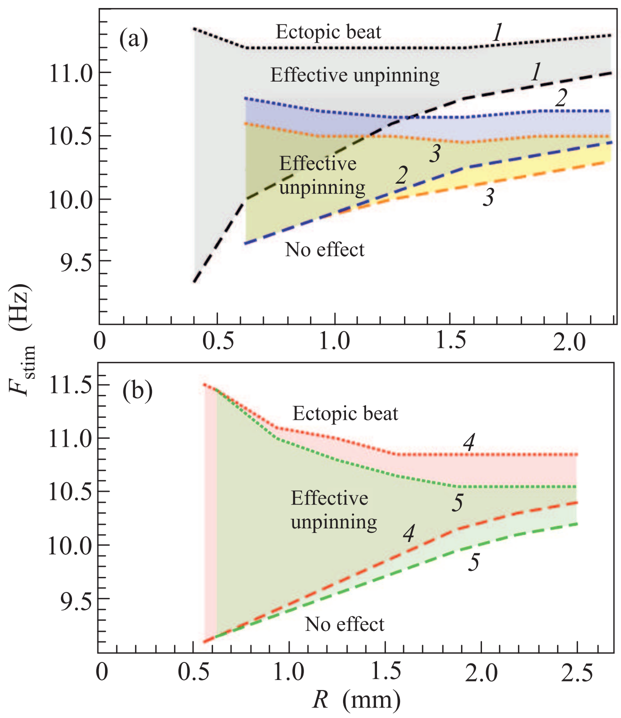

Fig. 1. (Color online) Frequency profile for unpinning of the reentry from a round defect. (a) – Dirichlet boundary with fixed potential – 72 mV (black, *1*) −60 mV (blue, *2*), −50 mV (yellow, *3*) depending on the radius of the defect. (b) – Defect plays role of inactive defect, but still coupled with other cells (green, *5*) depending on the radius of the defect compared with case of non-coupled defect with no-flux boundary conditions (red, *4*). Dashed line shows the minimal frequency of unpinning and dotted line shows the maximal frequency. Filled zone indicates that unpinning is applicable, regardless of the phase of a spiral wave

NRVM monolayers [11]. The boundary conditions in the simulations were adjusted to fit the experimental data for a straight, one-dimensional border.

We have shown that the waves decelerate near the border formed by the cut, which evidences for the existence of leakage or excessive electrotonic load. There-

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fore, the properties of the traumatic borders appeared closer to the flux boundary conditions. The working window of the pacing frequencies which could be applied for successful reentry extinguishing, shrinks, and in some cases even disappears, Fig. 1 demonstrates working window for different boundary conditions.

The presented work demonstrates that the fluxes through the border of the defect in the cardiac tissue can significantly modify the excitation pattern, especially when it concern rotating excitation waves. The working gap for the unpinning (and following elimination) of reentry waves could be substantially reduced, making overdrive pacing procedure practically inapplicable. The study indicates that before choosing the appropriate method of reentry termination, one must carefully analyze the nature of possible injuries in the heart tissue, since it would determine the boundary conditions of the defects present in the tissue.

The work was supported by the Russian Science Foundation grant # 16-14-10091.

Full text of the paper is published in JETP Letters journal. DOI: 10.1134/S0021364017210019

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