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Experimental and computational studies on complex spiral waves in 2-D cardiac substrates

NENAD BURSAC, Duke University

A variety of chemical and biological nonlinear excitable media including heart tissue can support stable, self-organized waves of activity in a form of rotating single-arm spirals. In the heart tissue, stable single-arm spirals can underlie highly periodic activity such as monomorphic ventricular tachycardia (VT), while unstable spirals that continuously form and break up are shown to underlie aperiodic and lethal heart activity, namely fibrillation. Although fast pacing from a point in the heart is commonly used to terminate VT, it can occasionally yield a transient or stable acceleration of tachicardia rate and/or fibrillation. In this study we tested the effect of rapid point pacing on sustained spiral waves in the uniformly anisotropic cultures of cardiac myocytes. In 15/79 cultures, rapid pacing induced a stable formation of multiple bound spiral waves (a complex spiral) and acceleration of overall excitation rate in the tissue, as assessed by pseudo ECG (pECG). The level of rate acceleration correlated with the number of rotating waves. Further rapid point pacing decelerated, terminated, or further accelerated the complex spiral activity via a change in the number of coexisting rotating waves. The dynamic restitution analysis revealed no alternans in action potential duration in any of the cultures. Stable formation of complex spirals was accomplished only in the cultures that showed relatively broad and steep impulse wavelength and conduction velocity restitutions. A necessary condition for rate acceleration in a medium with monotonic restitution is that the rate of rotation of a single spiral wave is significantly lower than maximum sustainable rate of excitation in the medium. Preliminary data in a homogeneous medium using 3-variable Fenton-Karma (FK) based model of cardiac tissue suggest that decrease of fast inward current (excitability) can shift the spiral rate away from the break point on the restitution curve, enabling a necessary condition for rate acceleration.