Predicting Unpinning Success Rates for a Pinned Spiral in an Excitable Medium

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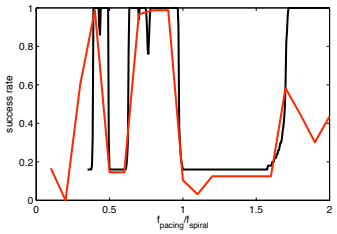
Today, the only robust technique for terminating ventricular fibrillation is an electrical shock of up to 400 joules. A reliable alternative to this procedure is desirable, as the strong currents of the shock may result in cardiac lesions and therefore may increase the risk of further arrhythmias. To understand how other, more gentle, pacing protocols could lead to a termination of ventricular fibrillation, it is crucial to clarify the underlying mechanisms.

Fibrillation and other life-threatening cardiac arrhythmias are associated with the existence of spiral waves in the tissue. Their termination by conventional anti-tachycardia pacing (ATP) is substantially limited by anchoring of these waves at natural heterogeneities. Far-field pacing (FFP) is a control strategy that has been shown to be capable of unpinning waves from obstacles. For the application of several periodic pulses, the success of unpinning is determined by the initial position of the spiral as well as by the pacing frequency. Therefore, we systematically study the response of a pinned spiral wave to a series of periodic FFP-pulses in a generic model of excitable media for a broad range of pacing frequencies. From the phase response of the spiral to a single pulse only, we construct an iterative map for the response to multiple pulses. For pacing frequencies lower than the spiral frequency, the map accurately predicts the phase response and the unpinning success rate for further pulses. For high pacing frequencies, however, the phase response predicted by the iterative map deviates from the results obtained by direct numerical simulations due to the interactions of consecutive pulses. We identify and discuss the mechanisms underlying this frequency-dependent deviation.



Prediction of (a) the success rate for 8 periodic FFP stimuli for different pacing frequencies (b) the resulting phase ϕ after 2 pulses ($f_{\mathrm{pacing}}/f_{\mathrm{spiral}} = 0.8$). Black: prediction by the iterative map. Red: success rate determined by direct simulation (in steps of 0.1).