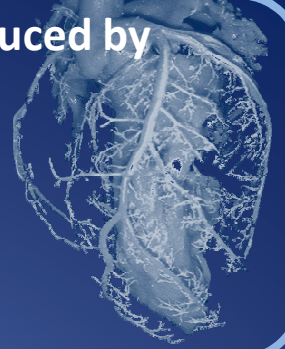


Effects of temperature on pacemaker activity induced by mechano-electric feedback in a one-dimensional model of cardiac fiber



A. Collet^{1*}, T. Desaive¹, P. C. Dauby¹

¹Cardiovascular Research Center, University of Liège, Liège, Belgium

Introduction

The mechano-electric feedback (MEF) in the heart consists in the influence of the tissue deformations on the cardiac electrical activity. Under certain conditions, tissue deformations can generate electrical perturbations via stretch-activated channels, such that the membrane potential can exceed the threshold value needed in order to trigger cardiac action potentials (APs). In the present study, we have developed a one-dimensional model of cardiac fiber taking into account three different couplings: the excitation-contraction coupling (ECC), the MEF and the thermoelectric coupling (TEC). The main goal of this work is to examine the effects of the TEC on the different properties of the pacemaker activity generated by the MEF.

Modeling

The model equations

$$\tau_m \partial_t V = \lambda_m^2 \partial_{x^M} (\sqrt{C} C^{MN} \partial_{x^N} V) + \eta(T) [f(V, w) - I_{SAC}] \quad (1)$$

$$f(V, w) = kV(a - V)(V - 1) - w \quad (2)$$

$$\tau_m \partial_t w = \varepsilon(V) \varphi(T) (kV - w) \quad (3)$$

$$\tau_m \partial_t T_a = \varepsilon(V) (k_{T_a} V - T_a) \quad (4)$$

$$S^{MN} = S_p^{MN} (C^{MN}) + S_a^{MN} (C^{MN}, T_a) \quad (5)$$

$$\partial_{x^M} (S^{MN} \partial_{x^N} x^i) = 0 \quad (6)$$

$$I_{SAC} = G_{SAC} (V - E_{SAC}) (\sqrt{C} - 1) \Theta(C - 1) \quad (7)$$

Excitation-contraction coupling: The ECC is given by linearly superimposing to the passive stress (given by a Mooney—Rivlin-type model) the active stress components, which depend on the active tension T_a given by (4).

Mechano-electric feedback: The MEF is provided by incorporating the stretch-activated currents (7) in the monodomain equation (1). These currents are modeled by using a generic description.

Thermoelectric coupling: $\eta(T) = A[1+B(T-T_0)]$ and $\varphi(T) = Q_{10}^{(T-T_0)/10}$ are 2 temperature-dependent functions describing respectively the temperature dependence of the ionic conductances and the gating kinetics of ionic channels (T_0 is a reference temperature).

(1), (2), (3) and (4): cell model; (5): mechanical constitutive law; (6): mechanical equilibrium; (7): stretch-activated currents (SACs)

Results

Figure 1

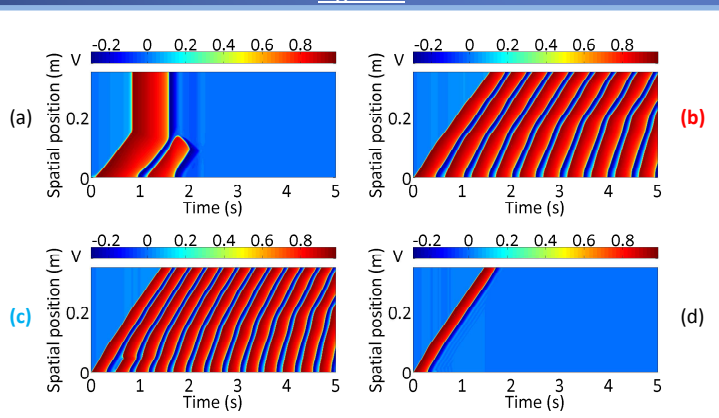
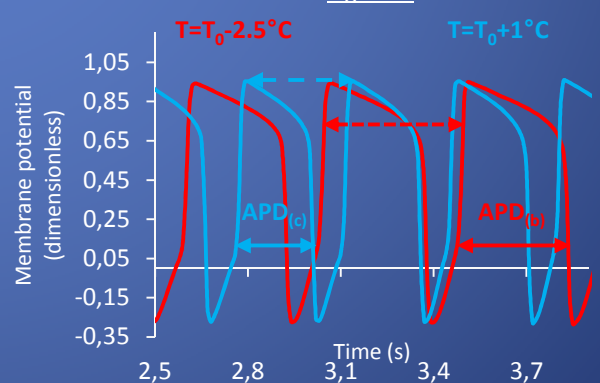


Figure 2



▪ The time oscillatory behavior of the membrane potential V (pacemaker activity) is sustained by the MEF only inside a given interval of temperature $[T^*, T^{**}]$ where $T^* = T_0 - 9^\circ\text{C}$ and $T^{**} = T_0 + 1.5^\circ\text{C}$ (Fig. 1a and Fig. 1d). Fig. 1b and Fig. 1c show 2 intermediate cases, $T = T_0 - 2.5^\circ\text{C}$ and $T = T_0 + 1^\circ\text{C}$, respectively.

▪ The mean action potential duration (APD) decreases when the temperature increases (Fig. 1 and Fig. 2).

▪ The mean time interval between two successive APs, generated by the MEF, at a fixed spatial point in the cardiac fiber (spatial position = 0.1743 m), dramatically decreases when the temperature increases (Fig. 2).

Conclusion and perspective

Our numerical simulations have highlighted that the TEC significantly influences the MEF. The next step is to introduce the TEC in a 2D electromechanical model in order to examine the influence of the TEC on the spatio-temporal behavior of spiral waves.

Financially supported in part by the French Community of Belgium (Actions de Recherches Concertées—Académie Wallonie Europe)

*Fellowship Beneficiary—Research Training Fund for Industry and Agriculture, e-mail: A.Collet@ulg.ac.be