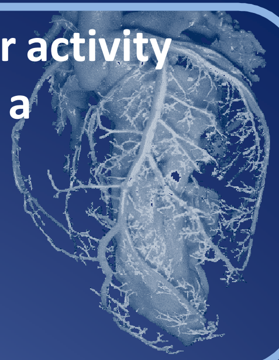
Influence of thermoelectric coupling on pacemaker activity generated by mechano-electric feedback in a one-dimensional ring-shaped model of cardiac fiber



A. Collet[1]*, T. Desaive[1], L. Piérard[1], R. Boman[2], P. C. Dauby[1]

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

[2]Computational Mechanics Laboratory, 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 ring-shaped 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

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

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

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

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

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

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

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

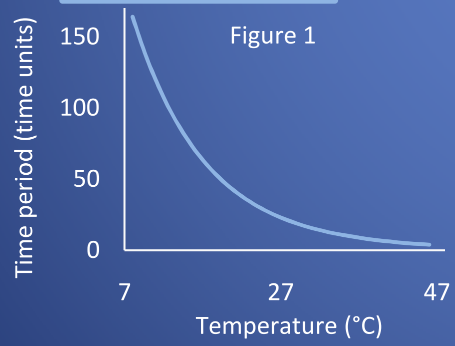
Excitation-contraction coupling: The ECC is given by linearly superimposing to the passive stress (given by a Mooney—Rivlin-type model) the active stress components, which depend on the active tension T_a given by (4).

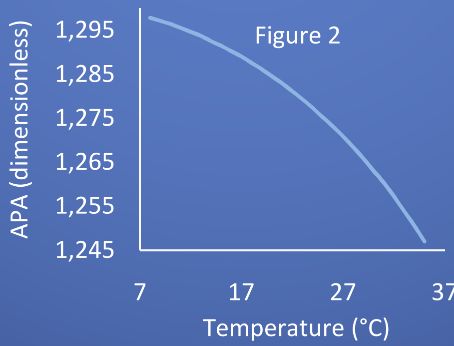
Mechano-electric feedback: The MEF is provided by incorporating the stretch-activated currents (7) in the monodomain equation (1). These currents are modeled by using a generic description.

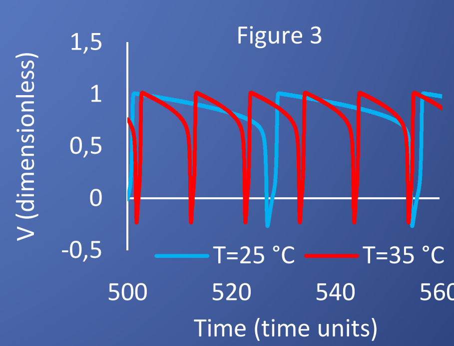
Thermoelectric coupling: $\eta(T) = A[1+B(T-T_0)]$ and $\varphi(T) = Q_{10}^{(T-T_0)/10}$ are 2 temperature-dependent functions describing respectively the temperature dependence of the ionic conductances and the gating kinetics of ionic channels (T_0 is a reference temperature).

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

Results







- The time period between two successive APs, generated by the MEF, at a fixed spatial point in the cardiac fiber, dramatically decreases when the temperature increases (Fig. 1).
- The action potential amplitude (APA) decreases when the temperature increases (Fig. 2).
- The action potential duration (APD) decreases when the temperature increases (Fig. 3).
- The time oscillatory behavior (Fig. 3) of the membrane potential V (pacemaker activity) is sustained by the MEF only inside a given interval of temperature [T*,T**]. Interpretation: for T<T*, it can be shown that SACs are too weak to trigger an AP. In turn, for T>T**, SACs have been shown to be large enough to theoretically trigger an AP but the cardiac tissue is still in a refractory state when these currents appear.

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