INFLUENCE OF THERMOELECTRIC COUPLING ON PACEMAKER ACTIVITY GENERATED BY MECHANO-ELECTRIC FEEDBACK IN A ONE-DIMENSIONAL RING-SHAPED MODEL OF CARDIAC FIBER

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SUMMARY
Recently, the influence of thermal processes on electrophysiology has clearly been underlined by Bini et al. [2], using a FitzHugh–Nagumo-type (FHN-type) model. When the temperature is raised, the action potential duration (APD) has been shown to shorten, while the action potential (AP) amplitude decreases, and the conduction velocity increases [2]. In the present study, we investigate the effects of thermoelectric coupling on mechano-electric feedback (MEF), and more specifically, on pacemaker activity generated by MEF. To investigate these effects, thermoelectric coupling is introduced in a one-dimensional ring-shaped electromechanical model of cardiac fiber, which takes into account excitation-contraction coupling (ECC), as well as MEF.

INTRODUCTION
The electrical activity of the heart generates an active tension that induces the cardiac tissue deformations. Therefore, it is evident that the mechanical behavior of the heart is heavily dependent on the electrical activity. In turn, the mechanical behavior affects the electrical activity due to different cellular mechanisms such as stretch-activated currents (SACs). In addition, it is well known [2,4,5] that the thermal processes significantly affect the electrical properties of cardiac tissue. In this research, we propose to introduce the thermal component in an electromechanical model in order to examine the effects of thermal processes on pacemaker activity generated by MEF in a one-dimensional ring-shaped model of cardiac fiber.

METHODS
Our starting point is a simple model (Figure 1) that includes all the key ingredients required to investigate the qualitative electromechanical behavior of cardiac tissue such as pacemaker activity induced by mechanical deformation [1,6]. In this model, electrical activation is described by a two-variable FHN-type model. Active tension, generated by electrical activation, is directly coupled to the transmembrane potential to account for the basic delay between the initial fast inward currents and the final actin-myosin contraction [1]. The mechanical behavior of cardiac tissue is modeled by the non-linear stress equilibrium equations governing large deformations. In addition, a Mooney-Rivlin model is chosen to describe the passive mechanical behavior of cardiac tissue. ECC is given by linearly superimposing to the passive stress the active stress components, which depend on the active tension computed in the cell model [1,6]. The influence of contraction on excitation, namely the MEF, is provided by including stretch-activated currents in the well-known monodomain equation [1,3,6,7,8].

The influence of thermal processes on electrophysiology is taken into account by adding thermoelectric coupling (TEC) in the electromechanical model (Figure 1), in a similar way as in the Bini et al. [2] study.

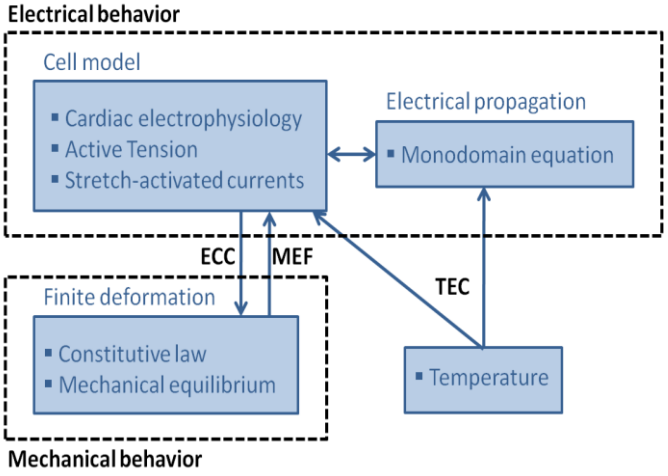

Figure 1: Conceptual scheme of the computational model. Three different couplings are taken into account: excitation-contraction coupling (ECC), mechano-electric feedback (MEF) and thermoelectric coupling (TEC).

It is widely believed that the deformation of the heart occurs on a longer timescale than the electrophysiology of the heart [7,8]. This is an attractive assumption from a computational viewpoint. Indeed, due to this assumption, the deformation of the heart can be updated using a time step bigger than that used to calculate the numerical solution of the equations modeling the electrical activity. Note also that the nonlinear system resulting from the mechanical equilibrium is solved by performing Newton-Raphson iterations.

With regard to the temporal discretization, a forward Euler scheme is used for all time derivatives. In addition, the second spatial derivative in the monodomain equation is discretized with a finite difference method, namely a central difference

scheme. Moreover, the two partial differential equations (monodomain and mechanical equilibrium equations) are subjected to periodic boundary conditions so as to obtain a one-dimensional ring-shaped model of cardiac fiber.

RESULTS AND DISCUSSION

Our numerical simulations have shown that the thermal processes significantly affect the electromechanical behavior of cardiac tissue.

When the temperature is raised, the interval between two successive APs dramatically decreases (Figure 2). There is even a critical temperature above which pacemaker activity is not generated by MEF anymore. This behavior can be explained in the following way. After that a first AP is generated by the initial depolarization, the following APs should be triggered by the SACs induced by the MEF. However, when the temperature exceeds the critical value, cardiac tissue is still in a refractory period when the SACs are large enough to initiate an AP.

Our simulations also show that the APD considerably decreases when the temperature increases (Figure 2), as previously described by Bini et al. [2].

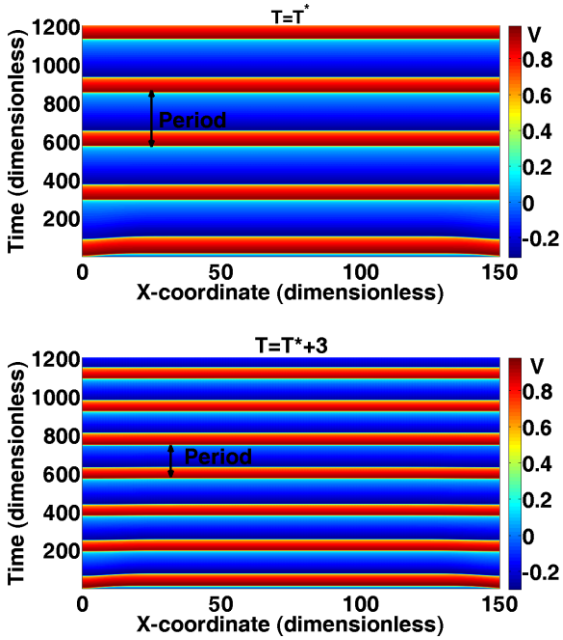

Figure 2: Shortening of the temporal period between two successive APs and APD when the temperature increases.

CONCLUSIONS

We developed a one-dimensional ring-shaped model of cardiac fiber which can be considered as a numerical tool in order to qualitatively address the question of the role of thermal processes on the electromechanical behavior of cardiac tissue.

Our numerical simulations have highlighted the significant influence of thermal processes on the pacemaker activity generated by MEF.

Future work will consider a more realistic geometry as well as improvement in the mathematical description of cardiac electrophysiology and mechanical behavior.

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