Computational modeling of non-linear diffusion in cardiac electrophysiology : a novel porous-medium approach

Hurtado, D. E., Castro, S., & Gizzi, A. (2016). Computational modeling of non-linear diffusion in cardiac electrophysiology: A novel porous-medium approach. Computer Methods in Applied Mechanics and Engineering, 300, 70-83. <10.1016/j.cma.2015.11.014> Accessed 29 Nov 2020.

Abstract

The electrophysiological behavior of excitable biological media has been traditionally modeled using a nonlinear reaction–diffusion equation commonly known as the cable equation. To account for the propagating nature of electrical waves, virtually all cardiac electrophysiology formulations proposed to date consider a linear diffusion flux, a constitutive relation known in biology as Fick's law. In this work, motivated by the porous nature of intercalated discs in cardiac muscle cells that mediate intercellular communication and ultimately tissue conductivity, we propose a novel formulation of cardiac electrophysiology that incorporates a nonlinear diffusion term of the porous-media kind. To solve the resulting system of non-linear partial differential equations we develop a non-linear implicit finite-element scheme that is suitable to simulations of large-scale cardiac problems. We show that the proposed porous-medium electrophysiology model results in propagating action potentials that have well-defined wavefronts and travel with finite speed. We also show that the proposed model captures the restitution properties of cardiac tissue similar to the cable model. We demonstrate the capabilities of our method by simulating the activation sequence of a three-dimensional human biventricular heart model, where important microstructural features like cardiomyocyte fiber orientation and the His–Purkinje activation network are successfully incorporated into the simulation.