NUMERICAL SIMULATION OF ACTIVE MECHANICS IN THE HEART: MUSCLE AND CELL SCALES

AYMEN LAADHARI, ALFIO QUARTERONI, SIMONE ROSSI, AND RICARDO RUIZ BAIER

Abstract. We investigate the interaction of intracellular calcium spatio-temporal variations with the self-sustained contractions in cardiac myocytes, and the related electromechanical behavior at the muscle level. A consistent mathematical model is presented considering an hyperelastic description of the passive mechanical properties of the cell and of the tissue, combined with an active-strain framework to explain the active shortening of myocytes and its coupling with cytosolic and sarcoplasmic calcium dynamics. A finite element method based on a Taylor-Hood discretization is employed to approximate the nonlinear elasticity equations, whereas the calcium concentration and mechanical activation variables are discretized by piecewise linear finite elements. Several numerical tests illustrate the ability of the model in predicting key experimentally established characteristics including: (i) Calcium propagation patterns and contractility, (ii) the influence of boundary conditions and cell shape on the onset of structural and active anisotropy, and (iii) the high localized stress distributions at the focal adhesions. Besides, they also highlight the potential of the method in elucidating some important subcellular mechanisms affecting e.g. cardiac repolarization.

Keywords: Active contraction, nonlinear mechanics, coupled multiphysics, finite element discretization.

Mathematics Subject Classifications (2000): 65M60, 74B20, 74F99.

References

[1] Bers DM. Cardiac excitation–contraction coupling. *Nature*, 415:198–205, 2002.

[2] Nobile F, Quarteroni A, Ruiz-Baier R. An active strain electromechanical model for cardiac tissue. *International Journal for Numerical Methods in Biomedical Engineering*, 28:52–71, 2012.

[3] Ruiz-Baier R, Ambrosi D, Pezzuto S, Rossi S, Quarteroni A. Activation models for the numerical simulation of cardiac electromechanical interactions. In: *Computer Models in Biomechanics: From Nano to Macro*, Holzapfel GA, Kuhl E (eds.), 2012, in press.

[4] Stålhand J, Klarbring A, Holzapfel GA. A mechanochemical 3D continuum model for smooth muscle contraction under finite strains. *Journal of Theoretical Biology*, 268:120–130, 2011.

[5] Tracqui P, Ohayon J. An integrated formulation of anisotropic force-calcium relations driving spatio-temporal contractions of cardiac myocytes. *Philosophical Transactions of the Royal Society of London Series A*, 367:4887–4905, 2009.

CMCS-MATHICSE-SB, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

E-mail address: aymen.laadhari,alfio.quarteroni,simone.rossi,ricardo.ruiz@epfl.ch