DY 19: Nonlinear Dynamics of the Heart: Contributed talks to focus session

Time: Wednesday 15:00–16:45 Location: MA 001

DY 19.1 Wed 15:00 MA 001

From Vascular Structures to Cardiac Activation Dynamics — •Daniel Hornung[1,2], Philip Bittihn[1,2], Amgad Squires[1], Flavio Fenton[1,3], and Stefan Luther[1,2,3] — [1]Max-Panck-Institut für Dynamik und Selbstorganisation Göttingen — [2]Institut für Nichtlineare Dynamik, Georg-August-Universität Göttingen — [3]Department of Biomedical Sciences, Cornell University

Under externally applied electric fields, heterogeneities in cardiac muscle tissue may serve as sources of cellular activation and thus emit waves of muscular excitation. This effect is most promising on the search for new, more gentle, low energy defibrillation techniques, and quantitative methods for assessing these heterogeneities and their effects on cardiac (de)fibrillation are of the greatest importance.

We show a method to convert the measured sizes of cardiac coronary blood vessels – one kind of the mentioned heterogeneities – into a prediction of the heart activation under external electric fields.

By using micro X-ray computed tomography images of heart tissue, we are able to automatically reconstruct the structure of the coronary arterial vascular tree. The blood vessel diameter distribution in this tree follows a power law, which can then be transformed, using know relations between size and excitability, into a prediction of the time required to activate the whole tissue by an electric stimulus of a given strength. The relation between activation time and electric field strength also follows a power law, where the two respective exponents can be easily converted into one another.

DY 19.2 Wed 15:15 MA 001

On the possible generation of atrial fibrillation by mutually interacting excitation sources — •Claudia Lenk[1], Gunnar Seemann[2], Mario Einax[3], and Philipp Maass[3] — [1]Institut für Chemie, Technische Universität Ilmenau, Germany — [2]Institut für Biomedizinische Technik, Karlsruhe Institute of Technology, Germany — [3]Fachbereich Physik, Universität Osnabrück, Germany

Atrial fibrillation (AF) is the most common arrhythmia of the heart which, amongst others, strongly increases the risk of stroke. As a possible new generating mechanism of AF we study the interaction of two pacemakers located in separate regions connected by a small bridge. In our setup the sinus node is considered as the primary pacemaker, while the secondary pacemaker is representing self-excitatory sources as ectopic foci and microreentrant circuits, which are often observed in the left atrium of AF patients. Our calculations are based on the model of Bueno-Orovio *et al.* (BO model) with a specific adaption of parameters to the electrophysiology of the atria. The results are compared to solutions of the more generic FitzHugh-Nagumo (FHN) equations in order to get insight how far mechanisms are specific to electrophysiological peculiarities of the atria. Three different types of irregular excitation patterns with similarities to fibrillatory states can be identified in the FHN model for certain frequency ratios of the two pacemakers, but only one of them is present in the BO model. The reason for the higher robustness of the regular states in the BO model is discussed as well as effects of electrophysiological remodelling on the dynamical excitation patterns.

DY 19.3 Wed 15:30 MA 001

Cardiac contraction and mechano-electric feedback promotes discordant alternans — Enric Álvarez-Lacalle[1], Markus Bär[2], Blas Echebarria[1], and •Markus Radszuweit[2] — [1]Dept. Física Aplicada, Universitat Politècnica de Catalunya, 44-50 Av. Dr. Maranón, 08028 Barcelona, Spain — [2]Physikalisch-Technische Bundesanstalt, Abbestr. 2-12, 10587 Berlin, Germany

By means of numerical simulations of the Fenton-Karma model with electromechanical coupling we investigate the effect of contraction on cardiac alternans. The study is confined to action potential propagation along a quasi-one-dimensional cable where the mechanoelectrical feedback on the membrane voltage results from stretch-activated currents. The electromechanical coupling is approximated by a global coupling term following Alvarez-Lacalle and Echebarria, Phys. Rev. E 79, 031921 (2009). Discordant alternans is often a precursor for life-threatening arrhythmias like ventricular fibrillation and is often caused by a steep slope of conduction velocity (CV) restitution curve. Here, we show that contraction switches the dynamics from concordant to discordant alternans even when the CV restitution curve is practically flat at the onset of alternans. This result demonstrates the need to include the mechanics of the tissue in models of electrical propagation.

DY 19.4 Wed 15:45 MA 001

Dynamical impact of structural heterogeneities in electrically-stimulated cardiac tissue — •Philip Bittihn[1], Marcel Hörning[2], and Stefan Luther[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Department of Physics, Graduate School of Science, Kyoto University, Kyoto, Japan

Acute heart rhythm disorders such as fibrillation that underly sudden cardiac death are one of the leading causes of death in the industrialized world. When fibrillation arises, normal rhythm is usually restored using electrical shocks. In the last decade, both experiments and computationally intensive numerical simulations have been aimed at modeling the underlying mechanisms and at the improvement of these control strategies. Here, we theoretically target a basic feature of cardiac tissue that leads to its heterogeneous response to electric fields: its complex geometry. We examine mathematically how the shape of both internal and external tissue boundaries modifies the changes in membrane potential induced by electric fields. The results are confirmed both in cardiomyocyte cell culture experiments and in numerical simulations. Furthermore, we examine numerically how stimulation protocol parameters influence the ability of heterogeneities to act as wave sources. These investigations open the way to a profound theoretical understanding of electric-field stimulation effects in cardiac tissue.

DY 19.5 Wed 16:00 MA 001

Negative tension of scroll wave filaments in cardiac tissue — •Sergio Alonso[1], Markus Bär[1], and Alexander V. Panfilov[2] — [1]Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, 10587 Berlin, Germany — [2]Department of Physics and Astronomy, Gent University, Krijgslaan 281, S9 9000 Gent, Belgium

Scroll waves are vortices that occur in three-dimensional excitable media. Scroll waves have been observed in a variety of systems including cardiac tissue, where they are associated with cardiac arrhythmias. The disorganization of scroll waves into chaotic behavior is thought to be the mechanism of ventricular fibrillation, whose lethality is widely known. One possible mechanism of scroll wave instability is negative filament tension. It was discovered in 1987 in a simple two variables model of an excitable medium. Since that time negative filament tension of scroll waves and the resulting complex, often turbulent dynamics was studied in many generic models of excitable media and physiologically realistic models of cardiac tissue. Here we discuss the relation of negative filament tension and tissue excitability and the effects of discreteness in the tissue on the generation of the negative filament tension. We discuss the application of the negative tension mechanism to computational cardiology, where it is regarded as a fundamental mechanism that explains differences in the onset of arrhythmias in thin two-dimensional and thick three-dimensional tissue.

DY 19.6 Wed 16:15 MA 001

Characterization of complex spatio-temporal dynamics in cardiac tissue and its potential use in tomographic imaging techniques — •Jan Christoph[2] and Stefan Luther[1,2,3] — [1]Heart Research Center, Göttingen — [2]Max Planck Institute for Dynamics and Self-Organization, Göttingen — [3]Dept. of Biomedical Sciences, Cornell University, USA

Complex electromechanical spatio-temporal dynamics are the underlying mechanisms beneath cardiac arrhythmia, including vortex-like rotating scroll waves. Fluorescence imaging (optical mapping) uses voltage sensitive dyes to provide high-resolution data of cardiac excitation waves; however, this technique is limited to the surface of the heart. For a better understanding of the underlying three-dimensional dynamics inside the tissue, new imaging techniques capable of resolving the electromechanical dynamics deep inside the heart are needed. We hypothesize that characteristic properties of three-dimensional spatio-temporal dynamics in cardiac tissue may be obtained from high-resolution strain measurements during the active contraction of the cardiac muscle and that these patterns reveal differences in physiological and pathological function of the heart. We compare strain patterns obtained in simulations of an elastic excitable medium with typical patterns occurring in experiments and discuss technical challenges and limitations that are involved with the experimental investigations.

DY 19.7 Wed 16:30 MA 001

Percolation-induced reexcitation in a discrete model for heterogeneous excitable cardiac tissue — Sergio Alonso and •Markus Bär — Physikalisch-Technische Bundesanstalt, Abbestrasse 2-12, 10587 Berlin, Germany

Arrhythmias in cardiac tissue are related with electrical wave propagation in the heart. Cardiac tissue is formed by a discrete network, which is often heterogeneous. It is shown by extensive simulation in a discrete model that a wave crossing a highly heterogeneous region of cardiac tissue may breakup and produce irregular patterns, when the fraction of heterogeneities is close to the percolation threshold of the cell network. The results are generic for heterogeneous excitable media and do not depend on the exact structure of the cells in cardiac tissue.