

Anatomically Detailed Patient-specific Closed-loop Modeling of Heart-pacemaker Interaction

N. Biasi, P. Seghetti, D. M. Vultaggio, M. Laurino, A. Tognetti

Research Center E. Piaggio, University of Pisa, Italy

Background: In the last few years, pacemaker implantation has increased to treat drug-resistant cardiac arrhythmias. Recently, it has been shown that the design and assessment of pacemakers can be enhanced by closed-loop modeling of heart-pacemaker interaction. In closed-loop models, the heart activity is typically represented by finite automata. However, reaction-diffusion models provide a more accurate representation of the cardiac tissue and may offer useful insights into heart-pacemaker interplay in a closed-loop approach.

Methods: We developed an anatomically detailed computational closed-loop model of whole-heart-pacemaker interaction based on patient-specific geometry. Beyond atrial and ventricular chambers, our model includes a fast-conduction system composed of the atrioventricular node and the His-Purkinje complex. Fiber orientation in atrial and ventricular tissue was assigned with rule-based methods. Action potential propagation in cardiac tissue was governed by the monodomain model, whereas in the fast conduction system, an Eikonal model was adopted. The atrioventricular node and Purkinje-muscular junctions are modeled with timed automata governing the connection between the muscular tissue and the fast-conduction system. The whole-heart model was coupled with a dual-chamber pacemaker model previously developed by our group. The pacemaker model processes the atrial and ventricular electrograms simulated by the heart model and coherently produces pacing stimuli. To demonstrate the functionalities of our framework, we analyze a pathological case of endless loop tachycardia, which arises when the pacing stimuli and the intrinsic heart activity interfere.

Results: Depolarization and repolarization sequences in our whole-heart model are coherent with clinical data in healthy and pathological scenarios. The closed-loop model can correctly emulate the heart-pacemaker interaction in endless loop tachycardia, sinus node dysfunction, and atrioventricular block cases.

Conclusion: Our closed-loop system provides a promising patient-specific environment for studying the interaction between the heart tissue and the stimulation device.



Whole-heart
depolarization