Towards the development of virtual heart technology for creating digital twins of cardiac electrophysiology

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Introduction: Virtual heart technologies promise to offer an anatomically accurate and mechanistically detailed view on human cardiac electrophysiology (EP). Such technologies when tailored to individual patients, called then digital twins, are considered highly promising in clinical and industrial applications. However, so far only very few virtual technologies simulating the entire organ-scale EP of four-chamber hearts have been reported and widespread use is limited due to factors such as computational costs, labor intense processing workflows and the difficulty of ascertaining a close match between simulations and observable physiological reality.

Objectives: Develop efficient workflows for both critical stages of creating a digital twin model of human cardiac EP, these are i) the generation of patient-specific anatomical models and ii) the calibration of an EP model to match clinical observations such as the electrocardiogram (ECG).

Methods: We developed an efficient twinning pipeline for creating anatomically accurate models from tomographic imaging data. This includes automated generation of multi-label segmentations from CT or MRI data using a convolutional neural network, a mesh generation step, and the assignment of tissue types and structural properties such as fiber architecture, as well as the incorporation of a cardiac conduction system. Functional twinning is based on data assimilation utilizing ECGs and electrograms, respectively. Derivative-free stochastic optimization methods as well as gradient based optimization algorithms are used to calibrate the underlying EP model to achieve a close agreement between simulation outputs and clinical measurements not used for calibration.

Results and Conclusion: We used our workflow to efficiently create a high fidelity whole heart digital twin model of a healthy volunteer, that replicates the measured ECG under normal sinus rhythm with high fidelity. We further demonstrate the mechanistic capability of this model by imposing pathological conditions such as bundle branch blocks or accessory pathways which produces ECGs meeting known diagnostic criteria.