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EDITORIAL

Personalized cardiac modeling and simulations in euHeart

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Heart disease represents a highly relevant and epidemiologically significant contributor to loss of quality and quantity of life. In Europe, cardiovascular disease (CVD) causes nearly half of all deaths or 4.3 million deaths a year [1]. CVD manifests itself in diseases such as coronary artery disease, congestive heart failure, and cardiac arrhythmias. These diseases have a significant impact on the EU economy with an estimated cost of EUR 192 billion a year [1]. This significant financial burden is spread across community sectors with approximately 57 % of costs due to direct health care costs, 21 % due to productivity losses and 22 % due to the informal care of people with CVD. Thus, the early detection and prediction of the progression of CVD are key requirements toward improved treatment, a reduction in mortality and morbidity, and of course to reduce healthcare costs.

Describing human anatomy, physiology and disease and predicting its behavior from patient-specific measurements is the ambitious goal of the wider virtual physiological human (VPH) initiative that provides a core element of the 7th Framework Programme of the European Commission. The euHeart project was a large-scale integrated project funded within this program and focused on the development of methods for the patient-specific modeling of the heart and its major diseases. In particular, the euHeart project focused on the treatment of cardiac arrhythmias with cardiac resynchronization therapy or by radiofrequency ablation, coronary artery disease and myocardial perfusion, congestive heart failure due to structural abnormalities leading to abnormal hemodynamic and loading, and abnormalities in hemodynamic and loading due to valvular or aortic disease. Its specific objectives were not only to improve our understanding of CVD, but also to improve diagnosis, treatment planning and delivery, and optimization of implantable devices by making cardiac models patient-specific using clinical measurements. The approach followed in the euHeart project was to divide the components of the project into two groups, technical tools building and advancing general technologies and applications focusing on specific cardiovascular diseases and therapies. Following the structure of the project, the papers within this special issue describe the individual contributions that have been integrated under the euHeart umbrella.

Two of the technical subprojects developed technologies that enable sharing of models with and reuse by the community. Kerfoot et al. [2] describe the Web-based anatomical models database (AMDB). This database has been populated with cardiovascular models from the consortium and extended with computing services facilitating building of cardiovascular models. Britten et al. [3] provide an overview of FieldML, an open standard for declaratively representing mathematical models. The focus of FieldML is on describing spatial–temporal variation and more generally, multidimensional differential and topological manifolds that build the basis for simulations.

In addition, two other papers describe the advancement of technologies for personalizing heart models and cardiac simulations within the project. Weese et al. [4] provide an overview over the euHeart algorithms for efficiently

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generating patient-specific anatomical models from medical images of multiple imaging modalities. In this context, also the integration of algorithms for anatomy extraction and physiological simulations has been addressed. Chapelle et al. [5] describe the fundamental principles of data assimilation underlying the Verdandi library that assimilates observations into a model by acting on the discrepancy between the measurements and the values derived from the computational model. This approach underpins the second technology that addresses personalization of model parameters that are not directly observable from available clinical data but play a key mechanistic role in the disease process. Examples within this project include the contractility of the cells in the myocardium or the material properties of the aortic wall.

Adaptation of models and simulation studies on the disease areas resulted in a wealth of new approaches, technical improvements and insights. Many of them were enabled by clinical data sets acquired during the project that comprise, for instance, data for model building as well as specific (invasive) acquisitions to enable model validation. Using comprehensive multimodal data sets corresponding to 8 patients, Tobon-Gomez et al. [6] discuss to what extent preoperative multimodal image data can improve our understanding of the mechanisms of CRT response and what in-silico electromechanical simulations can add to our understanding of intra-ventricular mechanical dyssynchrony. Krüger et al. [7] describe the progress toward personalized clinical in-silico modeling of atrial anatomy and electrophysiology, which is currently in a transition from the use in basic research to future clinical applications.

In addition to modeling electrophysiology, modeling of cardiac mechanics, blood flow and perfusion was also addressed. de Vecchi et al. [8] present a methodology for creating personalized ventricular models of blood and tissue mechanics to assess patient-specific metrics. The fluid–structure interaction simulations are used to analyze the diastolic function in hypoplastic left heart patients. Nolte et al. [9] present a review discussing myocardial perfusion distribution and coronary arterial pressure and flow signals in the context of coronary artery disease.

While not being comprehensive, the contributions demonstrate a significant part of the achievements of the euHeart project that resulted in more than 300 publications of which 128 have been published in peer-reviewed journals. The project demonstrated the predictive value and clinical potential of personalized cardiac simulations for several clinically relevant settings. Clinical validation for a large number of patient cases needs to be done in future projects.

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