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Toward Patient-Specific Myocardial Models of the Heart

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Integrating computational models of the heart with clinical data can open up ways to improve diagnosis, treatment planning, and interventions for cardiovascular diseases. It provides a consistent, biophysically based framework for the integration of the fragmented and heterogeneous clinical data currently available. Obtaining patient-specific computational models of the cardiac physiology could help diagnosis by providing physically meaningful cardiac indices. Moreover, once validated, models can have a predictive use and guide in patient management and therapy planning. For example, these computational models provide an excellent basis to optimize the design of implantable devices for improved therapy. However, the application of this modeling research has yet to be translated into the clinical environment, mainly because of the difficulty of validating these models with in vivo data, and efficiently personalizing them.

There is a growing body of literature on the functional imaging of the heart, for example with the measurement of electrical activity, deformation, flows, fiber orientation [1–4], and on the modeling of the electrical and mechanical activity of the heart [5–9]. Many of these models are direct computational models, designed to reproduce in a realistic manner cardiac activity, often requiring high computational costs and the manual tuning of a very large set of parameters.

The proposed approach is to design models that are directly related to the phenomena observed in clinical data. Although the models used here are often simplified when compared with the very detailed models available in the literature, the authors try to select a level of modeling compatible with reasonable computing times and involving a limited number of parameters, thus allowing the identification of the model parameters from clinical measurements of a specific patient, through the resolution of the inverse problem (Fig. 1).

There are still many challenges in achieving a patient-specific electromechanical model of the heart, but some parts can already be personalized, as demonstrated here. The authors will present this work in three sections concerning the anatomy, the electrophysiology, and the biomechanics. But the first challenge in this area is to obtain patient data on these different parts, and integrate them in the same spatio-temporal coordinates.

Clinical data acquisition and fusion

The construction, testing, and personalization of biophysical models rely on the ability to fuse

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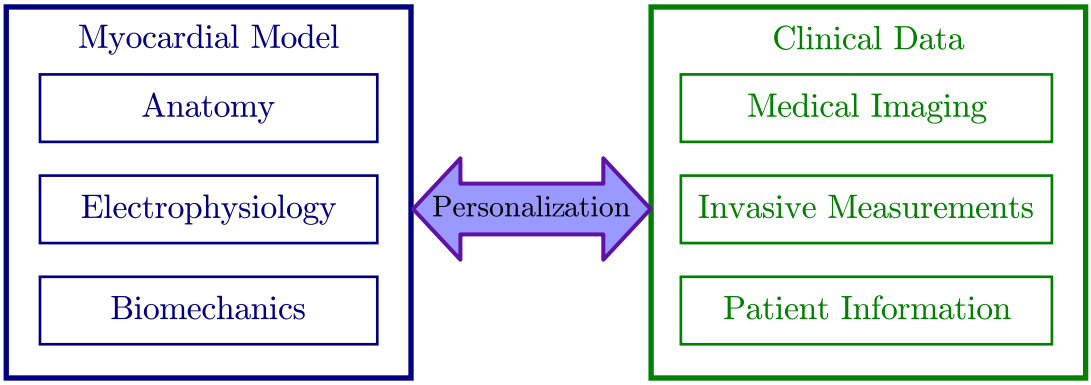

Fig. 1. Global scheme of the model building blocks and of the clinical data used to personalize it.

data from a variety of sources. For cardiac modeling, the fusion of anatomic, mechanical, and electrical data is of primary interest. This fusion must be both in the spatial and temporal domains. High quality cardiac anatomic data can be obtained from both computerized tomography (CT) and magnetic resonance imaging (MRI). MRI can also be used to obtain functional data, such as myocardial wall motion and blood flow. Electrical data can be obtained from catheter-based measurements that are guided using X-ray fluoroscopy.

Spatial fusion of these different data requires an effective image registration strategy. The authors' solution has focused on the use of the X-ray/MR (XMR) hybrid imaging system that allows the seamless collection of both MRI and X-ray-based data (Fig. 2). The authors have developed a real-time registration solution [10] that allows the spatial integration of MRI-based anatomic and functional data with X-ray-based catheter data, such as intracardial electrical and pressure signals. For the temporal integration, the electrocardiogram gives information on the heart rhythm that makes possible the synchronization of the different datasets.

Myocardial anatomy

In the authors' approach, only the compact biventricular myocardium is considered. As the valves are not modeled, the papillary muscles are not simulated, and only the atria and arteries as

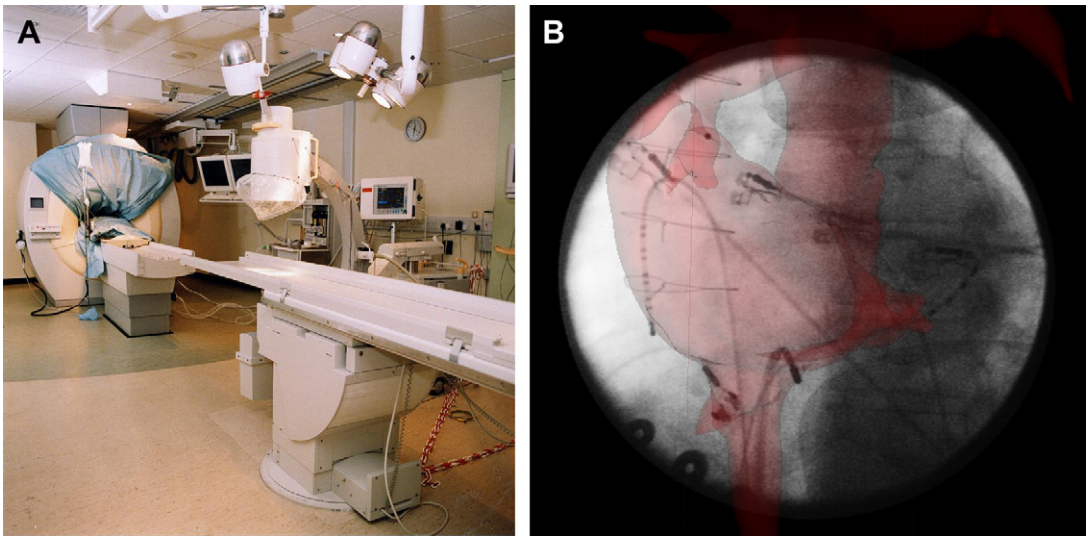

Fig. 2. (*A*) XMR suite with the MR scanner and the X-ray C-arm. (*B*) Catheters in place during an atrial flutter ablation and overlay of the MR-derived anatomy (*in red*) of the right side of the heart.