The Project

iHEART, which refers to "integrated heart model for the simulation of the cardiac function", represents one of the first attempts in the world to create a complete mathematical model of the human heart, which includes all the physiological processes that together form the complexity that we call life: the electrical, mechanical and fluid-dynamic processes and the electro-chemical one, at the cellular level. The project has been funded with ERC of 2.35 million euros from the European Union.

The research team will exploit the potential of mathematical analysis, numerical approximation and computational resolution to treat clinically relevant cases.

The ultimate goal is to build a virtual model of the heart that is able not only to minutely describe the interactions that take place within it, but also possibly to predict the dynamics, with the aim of building an instrument capable of helping clinicians study the genesis and treatment of cardiovascular diseases.
Possessing an integrated model of cardiovascular processes could improve prevention, treatment and cardiac surgery.
iHEART can be assimilated to a virtual microscope, in which cardiovascular diseases and their evolution are seen through complex equations that the research team aims to solve.

Interview with Alfio Quarteroni

Professor Quarteroni, can you explain the goals of iHEART more specifically?

Our main goal is to achieve a better understanding of cardiac function by resorting less to expensive and invasive examinations for the patient. We want also to help the doctor to understand how to intervene in case of diseases and, if there is a need for surgery, to assist him in choosing the best operative strategy. It will also allow the physician to realize scenarios of the evolution of particular clinical conditions, difficult to obtain with the tools of traditional medicine. More specifically, we would like to: integrate in a single mathematical model for the different processes of cardiac function: electrophysiology, the mechanical deformation that allows the contraction and relaxation of the heart muscle, the fluid dynamics of ventricles and atria and the interaction with the valvular dynamics, and ultimately, the coupling of the cardiac circulation with the systemic and pulmonary one; solve this numerically great system of differential and non-linear equations, with multiphysics and multiscale characteristics. In the end, we want to address issues of clinical relevance to cardiologists and cardiac surgeons operating in numerous national and foreign hospitals.

What impact do cardiac and cardiovascular diseases have on the population?

Eurostat data confirm that the diseases of the circulatory system in 2014 were the cause of death for 1,833 million people in the European Union: over a third (37%) of all deaths in the EU. Women (994,600 deaths) were more affected than men (838,100). In addition, fatal heart disease was responsible for 40% of all deaths in the EU population over 65 and for less than a quarter (22%) for the younger population (aged under 65). Heart attacks remained the main type of fatal cardiac disease in the EU and led to the death of nearly 623,100 people (34% of all deaths caused by diseases of the circulatory system), while strokes killed almost 422,000 people (23%).

As for Italy, however, Istat presented for the years 2003-2014 the complete historical series of mortality data by cause, which allows a thorough reading of the dynamics of the phenomenon in the long term. This document made it possible to clarify that in 2003 and in 2014 the first three causes of death in Italy are ischemic heart diseases, cerebrovascular diseases and other heart diseases (representing 29.5% of all deaths), although mortality rates for these causes have been reduced by over 35% in 11 years.

Has mathematics always been useful for understanding the behavior and functionality of the heart?

Two decades ago, mathematics could already be applied in the cardiovascular field to simulate, for example, the possible formation of atherosclerotic plaques and the consequent reduction of the lumen of an artery, such as the carotid. The goal was to understand the process of formation and evolution of the plaque and the changes it creates in the blood flow. Since then, interviewed by doctors to help them better understand the complex problems, mathematicians have developed increasingly sophisticated models, to the point of simulating the entire human circulatory system with mathematics.

On the whole, it is a three-pole advancement: a more in-depth understanding of physiology translated into increasingly effective equations that corresponds to the creation of powerful algorithms and the use of supercomputers.

What knowledge will be put together to implement iHEART?

In order to develop such a model, it is indispensable to take into account the interaction of the four main physical components that participate in the functioning of the heart: the electric one that generates an extracellular potential that propagates from the Purkinje fibers to the whole myocardium, the mechanical component given by the deformation of the cardiac structure, the fluid field of the blood that originates a vertical motion in the ventricles and in the atria, and finally that due to the valve opening and closing.

The non-linear virtuous interaction between these fields allows the heart to be that extraordinary machine that we try to describe with equations. To solve the electric field alone, the model must be translated into an algorithm that solves tens of millions of unknowns. For the fluid component, it can serve hundreds of millions.

In order to describe such fields, we have to develop models able to move along different space and time scales: from the micrometer used in electrophysiology to the centimeter scale for the dynamic of the cardiac organ, from microseconds to one second as concerns the time scale.

Can you describe in detail some of the possible applications of iHEART?

There will be several applications for iHeart: it may help cardiologists spot the best area for ablations in the event of irregular behaviors of the electric field, as well as heart surgeons in optimizing the design of coronary bypasses. This model will make it possible to provide an important contribution to neonatal surgery procedures on babies with heart malformations. In such cases, surgeons must perform a procedure on babies with a heart as big as a walnut. It truly is a challenging procedure that implies high risks. iHeart will help to plan such procedures in a personalized way, in order to implement a patient-specific kind of medicine: Big Data will allow for the implementation of libraries rich in data obtained from extremely accurate mathematical simulations, to be used as an aid for surgical procedures on new patients. Thanks to this huge data bank, it will be possible to adapt to new patients the information we already know, without having to build everything from scratch again.

Why is iHEART realizable now and was not previously?

Today we still don’t have the mathematical knowledge and the processing power necessary to implement a model such as iHeart, but in five years, we can hope that the model will be completed. We are not yet able to put together the components that describe the complexity of the cardiac system. It takes a week’s time on the largest European computer to simulate a single heartbeat. In five years, the dream is to realize simulations in real time. We hope to build a virtual copy of the heart, which will be available on tablets and smartphones to all the physicians in the ward ,and developed entirely in Italy.

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