MEMÓRIAS
DA
ACADEMIA DAS CIÊNCIAS
DE
LISBOA

CLASSE DE CIÊNCIAS

TOMO XLVII
Volume 2

A virtual mathematical heart for non-invasive heart diagnostics

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ACADEMIA DAS CIÊNCIAS
DE LISBOA

LISBOA • 2020

A virtual mathematical heart for non-invasive heart diagnostics

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One day, a virtual version of your own heart pumping may help doctors diagnose heart disease and determine the best treatment for you, without the need of surgical intervention or other invasive clinical practices. With my team at Politecnico di Milano in Italy we are actually building a mathematical model to simulate heart function with increasing accuracy and that can be personalized to your heart based on medical scans.

The human heart is an extraordinarily complex organ that pumps an estimated 180 million liters of blood, which would fill more than seven Olympic-sized swimming pools in one's lifetime, thereby ensuring that oxygenated blood reaches the entire body. Cardiovascular problems may lead to malfunction, disease or death. Heart disease causes 40% of deaths in the EU and costs an estimated 196 billion a year, yet 80% of acquired heart diseases and stroke episodes are preventable.

Our aim is to help prevent or treat cardiovascular disease by providing a personalized virtual heart to patients, essentially a detailed mathematical description of a patient's heart and how it functions – or malfunctions.

Every person's heart is unique. Correctly modeling the intricacies of each individual heart therefore requires a customizable mathematical description of both its geometry and its dynamics. But doing so in a mathematically sound way is no easy task; it requires large amounts of patient-specific data and computational power to solve complex equations. Thanks to increasingly powerful computers, building a realistic virtual heart is becoming a reality.

In constructing a virtual heart that is complete and functional, the aortic valve cannot be neglected. For that, we have recently added to our heart model the way blood flows from inside the heart into the aorta, taking into account the complex shapes and properties of the aorta's physiological membranes: the valve leaflets.

From MRI scans of a patient, we reconstructed the shape of the aorta, which we represented using a 3D computational mesh. Using mathematical tools to characterize the mechanics of the valve, we described the movement of three triangular-shaped leaflets that make up the aortic valve. To determine how blood flows inside of the atria, the heart's cavities, we next approximated and numerically solved the mathematical equations dynamics, adapting them for a patient-specific geometry. Even with this preliminary work, it is a relatively easy task to personalize the model to another patient by using a new set of MRI scans.

Our long-term vision is to build patient-specific virtual models of the entire cardiovascular system, including the heart, all of the body's blood vessels, and of the approximately five liters of blood flowing through the body.

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If successful, our model will help clinicians to tackle important questions efficiently, both in diagnostics and treatment, with a tremendous impact for society. It will provide a unique, unprecedented research environment for exploring the heart with an immensely powerful and non– invasive mathematical microscope, making it possible to simulate cardiovascular disease, like carotid stenosis and aneurysms that can affect the heart, the abdomen, the brain and other parts the body.

We believe that a personalized virtual heart model may become clinically available in less than a decade. Earlier prototypes of the virtual model may be developed and tested sooner, possibly within a five-year horizon. This will require significant investment in the development of robust mathematical and numerical tools to simulate heart function that is tailored to a specific patient.

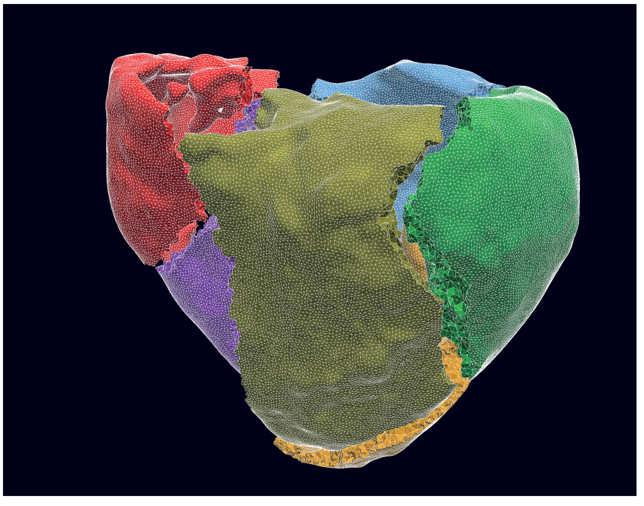

Fig. 1 The heart partitioned into multiple regions and with a finite element grid.

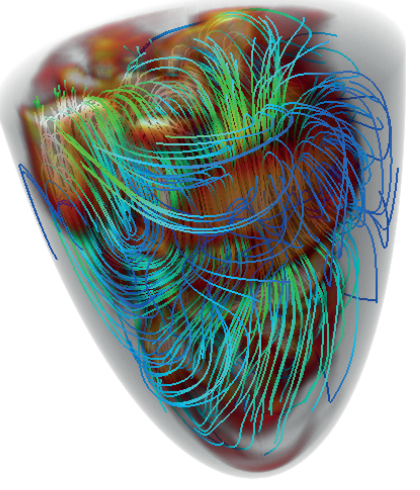

Fig.2. Blood flow streamlines in a left ventricle.

(Comunicação apresentada à Classe de Ciências na sessão de 22 de novembro de 2018)