A One-Dimensional Finite Element Model for Human Circulatory Systems

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***Index Terms*—Hemodynamics, Computational Biomechanics, Finite Element Method, Cardiovascular Mechanics, Respiratory Mechanics**

Extended Abstract

Cardiovascular disease and particle deposition in the human airways are some of the most critical issues in public health. Biomechanic simulations of the human cardiovascular and respiratory circulation, and electrical conduction systems address these concerns, enabling a further understanding of the physiological mechanics involved. These tools aid clinical diagnosis and have implications for the design of interventions such as surgical procedures, devices and aerosol drug delivery. The complexity of these systems motivate simplifying models capable of reproducing the main characteristics of interest, i.e.: wave propagation in the cardiovascular circulatory system, and particle-deposition in the respiratory system. Drastically reducing the computational cost, one-dimensional mathematical models are an option which has been extensively studied in application to blood circulation in arteries [1], and to a lesser extent to respiratory [2] and electrical conduction along fibres such as those contained in the Purkinje network [3].

Following the work of Formaggia et al. [4] we have developed a one-dimensional finite element model capable of reproducing the main wave-propagation characteristics in the human arterial system. With the objective of being able to run patient-specific simulations in the limited time frames required by practitioners, the algorithm is fully parallelizable between tubular segments so that it will provide HPC-grade efficient simulations. Our code allows the prescription of time-dependent boundary conditions making possible to couple with three-dimensional models. In particular, we plan to couple the one-dimensional model to the fully coupled fluid-electro-mechanical model of the human heart developed by Santiago et al. [5] and the large-scale Computational Fluid Dynamics model of human airways developed by Calmet et al. [6], both contained in Alya, the HPC multi-physics code developed at CASE, BSC [7].

We are currently in the process of parametrization and validation of the cardiovascular arterial model as well as optimizing the code to meet HPC efficiency requirements. In addition, we plan to develop the one-dimensional respiratory airways and electric fibre conduction models which will be coupled to the aforementioned codes.

Acknowledgments

The research leading to these results has received funding from "la Caixa" Foundation. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 713673.

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David Oks received his Licenciatura degree (equivalent to MSc degree) in Physics from the Universidad de Buenos Aires in 2017 and a MSc degree in Physics from the École Normale Supérieure de Lyon in 2018, specializing in experimental fluid dynamics. In 2018 he was awarded the la Caixa INPhINIT Fellowship Grant for Doctoral Studies at Spanish Research Centres of Excellence. He is now a PhD student at the Barcelona Supercomputing Center where his research focuses on simulations of the human arterial system and heart valves.