DATA-DRIVEN FSI SIMULATION OF VENTRICLE AND AORTA INTEGRATING IN VIVO AND IN SILICO DATA

Martino Andrea Scarpolini (1,2), Giulia Piumini (3), Filippo Cademartiri (4), Simona Celi (1) and Francesco Viola (4)

1. BioCardioLab, Fondazione Toscana Gabriele Monasterio, Italy; 2. University of Rome "Tor Vergata", Italy; 3. University of Twente, The Netherlands; 4. Clinical Imaging Department, Fondazione Toscana Gabriele Monasterio, Italy; 5. GSSI (Gran Sasso Science Institute), L'Aquila, Italy.

Introduction

The integration of in silico and in vivo data is crucial to the development of high-fidelity digital twins of the cardiovascular (CV) system, but is a challenging task that requires specific imaging techniques and in silico setups. Advancements in imaging technologies are making it possible to gather a large amount of patient information. In parallel, in silico models are becoming a useful tool to simulate patient-specific conditions, treatments and therapies. However, the latter models require a large amount of physical parameters to be known, which are often very difficult to measure in vivo. In this study, we used data-assimilation techniques to merge high-resolution temporal CT scans with fluid structure interaction (FSI) simulations, resulting in the creation of a high-fidelity digital twin of the left ventricle (LV) and aorta system of a patient.

Material and methods

Gated CT scans of a patient are used to obtain segmentations of the aorta and the LV. Triangulated surfaces are generated for each of the 20 phases available of the cardiac cycle, and lagrangian markers are defined on these surfaces and tracked over time employing a gradient-based registration method [1] (Figure 1A). An in-house code based on the Immersed Boundary method [2] is developed to perform data-driven FSI simulations (Figure 1B), using a hybrid structural model that employs the nudging technique [3] to conform to in-vivo data. A spring-network model is adopted for describing the dynamics of soft tissues. The nudging technique is used simultaneously in a point-wise and integral way. For anatomical regions where in vivo data is accurate, point-wise nudging can be used to follow each individual lagrangian marker. For noisy regions, on the other hand, the nudging is used to follow integral variables such as the overall volume and area of the myocardium. At each outlet of the aorta, the Windkessel model is used to simulate the peripheral circulatory system.

Results

The methods used in this study allow for the accurate reproduction of the kinematics of the cardiovascular structures, which is crucial in order to capture the patient-specific hemodynamics. In addition, the method has the ability to switch from a pure FSI simulation to a pure kinematics-driven simulation in a continuous manner by adjusting the relative magnitude between the

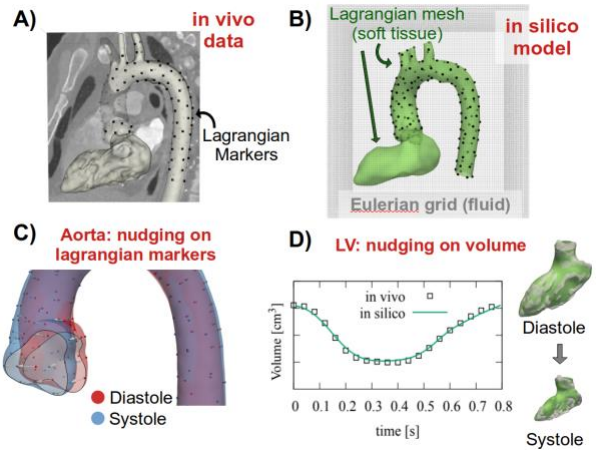

Figure 1: A) Visualization of in vivo data: thoracic CT scan and segmentation. B) In silico model setup. C) In silico aortic model: point-wise nudging. D) In silico LV model: nudging on volume and area.

nudging technique and the structural model. This allows for greater flexibility in the simulation process, as different scenarios can be tested in order to achieve the most accurate results. The use of different nudging techniques, depending on the kind and quality of the in-vivo data, further adds to the versatility and accuracy of the method. In the case of the aorta, point-wise nudging has been used (Figure 1C). For the LV, on the other hand, given the lower accuracy of in vivo data, nudging is used to follow integral variables: both the volume and area of the myocardium are used (Figure 1D).

Discussion

The combination of gated CT scans and FSI simulations has enabled the creation of an accurate CV model, representing a significant step towards the development of high-fidelity CV digital twins, despite limitations in available initial physiological parameters.

References

1. Scarpolini et al., ESB-2022 p. 101
2. Viola et al., Eur. J. Mech. B/ 79 - 2020
3. Di Leoni et al., Phys. Rev. X 10, 011023–2020

Acknowledgments

This project has received funding from the Marie Skłodowska Curie grant agreement No 859836. FV acknowledges the ERC Stg-project CARDIOTRIALS number 101039657.