PROJECT

Supervisor:	Prof. Antonio Esposito
Title:	CT-based patient-specific Cardiac Digital Twins for Non-Invasive Assessment of myocardial circulation
Curriculum:	Clinical and Experimental Medicine
Link to the personal page of the University or relevant hospital site website:	Esposito Antonio Università Vita-Salute San Raffaele

Description of the Project (max 3,000 characters including spaces)

Background/gap of knowledge

Myocardial ischemia can be associated both to obstructive disease of the epicardial coronary arteries and to microvascular dysfunction. Current first line imaging for the assessment of patients with suspected myocardial ischemia is usually the CT coronary angiography (CCTA). CCTA has good diagnostic performance in the assessment of epicardial coronary arteries but does not provide functional information about the microvascular function. Invasive measurements of myocardial micro-circulation physiology, PET imaging, and advanced MRI are costly and not widely accessible, leaving many patients without a clear diagnosis. Recent advances in photon-counting computed tomography (PCCT) provide high-resolution multiparametric cardiac imaging. Parameters extracted from PCCT may feed mechanistic cardiovascular models potentially providing the computational frameworks to enable non-invasive assessment of coronary microcirculation.

Rationale and hypothesis

This project aims to integrate high-resolution cardiac imaging with physiologically grounded computational models to develop patient-specific cardiac digital twins for predicting microvascular perfusion and ischemic risk. Scientific Machine Learning (SciML) methods, including physics-informed neural networks and latent dynamical models, enable the integration of imaging data with cardiovascular physiology. By embedding physical principles such as pressure-flow relationships into machine learning models, interpretable simulations of myocardial perfusion can be obtained. Hybrid models combining imaging-derived data with physics-informed learning are expected to reconstruct coronary perfusion patterns and detect microvascular dysfunction directly from CT data.

Objectives and specific aims

The main objective of this project is to develop a computational framework for constructing patient-specific cardiac digital twins capable of detecting coronary microvascular dysfunction from non-invasive imaging data. Specific aims include:
1 - Image-based parameter extraction: develop algorithms to process PCCT scans, including vessel segmentation, reconstruction of cardiac geometries, extraction of coronary flow and perfusion features;
2 - Digital twin modeling: integrate imaging-derived parameters into multiscale models of cardiac perfusion and coronary circulation, combining physics-based simulations with SciML approaches such as physics-informed neural networks and latent dynamical models;
3 - Model training and validation: train and evaluate the models using clinical datasets and synthetic cohorts generated by high-fidelity cardiac simulators;
4 - Risk indicator development: derive interpretable indicators of inducible ischemia, such as perfusion maps and flow-based metrics, capable of summarizing regional myocardial perfusion separating its underlying components (epicardial vessel stenosis and microvascular dysfunction).

Expected outcomes

The expected outcome of this project is a validated digital twin framework providing non-invasive insights into coronary microvascular function from CT imaging data. The models will generate physiologically interpretable outputs, improving the characterization of microvascular dysfunction. The project will also deliver methodological advances in SciML for integrating imaging data with mechanistic cardiovascular models. The resulting framework may support future clinical decision-support tools for personalized cardiovascular diagnostics.

Skills that the student should acquire (max. 600 characters including spaces):

The student will acquire skills in computational radiology, scientific machine learning, and digital twin modeling. Training will include advanced image processing of cardiac CT data, invasive hemodynamic data, multiscale cardiovascular modeling, and development of hybrid physics-informed machine learning models. The student will gain experience with state-of-the-art computational medicine models, numerical simulations, and model validation using clinical datasets, while working in an interdisciplinary environment bridging AI, mathematical modeling, and cardiovascular medicine.

References (max. 15)

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