PERSONALIZED COMPUTATIONAL MODELING OF MYOCARDIAL PERFUSION IN CORONARY ARTERY DISEASE

Giovanni Montino Pelagi (1), Andrea Baggiano (3), Francesco Regazzoni (2), Gianluca Pontone (3), Giovanni Valbusa (4), Christian Vergara (1)

1. LABS, Dip. Chimica, Materiali E Ing. Chimica, Politecnico Di Milano; 2. MOX, Dip. Di Matematica, Politecnico Di Milano; 3. Cardiovasc. Imaging Dept., Centro Cardiologico Monzino, Milan; 4. Bracco Imaging S.p.A., Milan

Introduction

Quantitative assessment of coronary blood flow and myocardial perfusion is of critical importance in the prognostic stratification of patients suffering from coronary artery disease. Since the most used clinical exams to this aim pose significant burden to the patient, computational approaches could be invaluable in providing relevant information in a non-invasive way. Still, many issues remain to be addressed to use them in a predictive way: tailoring the computational model to a specific patient, capturing the interplay between ventricle contraction and coronary hemodynamics, and accounting for pathological effects. Here, we developed a multiscale framework to run patient-specific simulations of hyperemic coronary blood flow, up to the microvasculature, to predict quantities of clinical interest in individuals with coronary artery disease.

Methods

Patients anatomy is reconstructed from CT angiographic images using segmentation tools. The multiscale perfusion model features a 3D description of hemodynamics in the epicardial arteries, coupled with a multicompartment Darcy formulation for the microvasculature, which also includes a treatment for microvessels compliance and ventricular contraction. Tailored pressure boundary conditions, representative of the hyperemic state, are built using routine clinical measures. Blood flow simulations are run in 8 patients using the in-house Finite Elements software LifeX.

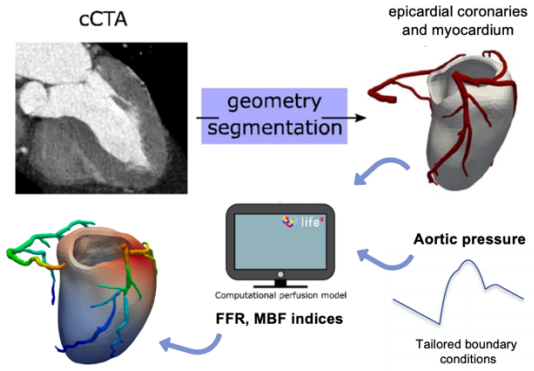

Figure 1: Steps of the personalized blood flow analysis.

Simulation results are post-processed to obtain the Fractional Flow Reserve (FFR_{CT}) and the Myocardial Blood Flow (MBF_{CT}) indices. The predictive power of the proposed framework is then assessed by direct comparison with measures of FFR and MBF from a clinical stress test, using a retrospective validation approach.

Results

In all the patients, the characteristic coronary phasic flow pattern with high arterial inflow in diastole and high venous outflow in systole was recovered. MBF maps show significantly higher values in patients with non-significant coronary stenosis having FFR > 0.8 (mean MBF = 289 ml/min/100g) with respect to patients with at least one lesion having FFR < 0.8 (mean MBF = 183,25 ml/min/100g). Myocardial perfusion defects associated with such lesions were also highlighted in the obtained MBF maps.

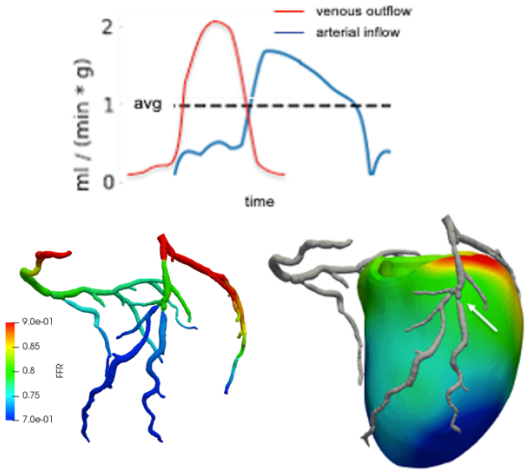

Figure 2: Top: flow patterns in the epicardial arteries and veins. Bottom: FFR_{CT} results showing significant lesions (left), MBF map with large perfusion defect and culprit lesion identified by the white arrow (right).

Discussion

FFR results show excellent agreement with the invasive value. Considering the clinical cutoff-based clustering (< 0.7, > 0.8 and in range 0.7-0.8), we achieved a per-vessel sensitivity and specificity of 95.8% and 100% respectively. MBF results show in general a good agreement with values obtained from the stress test, although we notice a slight yet non-negligible tendency in overestimating MBF in the more pathological cases. Indeed, mean MBF shows an absolute accuracy of 91% and 78% for patients without and with significant lesions, respectively. We believe that a more precise parametrization of the myocardium may solve this issue.