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COUPLING OF THE NAVIER-STOKES AND POROUS MEDIA EQUATIONS TO MODEL BLOOD FLOW IN THE CORONARY ARTERIES

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ABSTRACT

Introduction: Coronary perfusion (i.e. the delivery of blood flow to the coronary arteries) is an essential component of the heart's performance. Blood is delivered first to the larger arteries, which lie on the heart. The geometry of these vessels and the flow are highly three dimensional. These arteries then branch in smaller and smaller arteries that dive into the myocardium (the heart muscle), eventually forming dense networks of vessels where flow is smoother. While the detailed geometry of the larger coronary arteries is accessible through imaging, the exact geometry of the dense network of smaller vessels is not.

Methods: we therefore propose to model perfusion of the heart with the coupling of two blood flow models of different complexities. In the larger arteries, the three-dimensional Navier-Stokes equations are solved in patient-specific geometries, while the rest of the arterial tree in the myocardium is represented by flow in a porous media, where the detailed geometry of individual vessels is not represented.
In order to perform the simulation in the larger coronaries, the generation of the computational mesh (the “coronary mesh”), starting from a patient’s imaging dataset, has been accomplished. On the other hand, the myocardium is represented more crudely. The inlet surface of the “myocardium mesh”, the epicardium, has been divided in different patches, everyone “nourished” by a selected branch of the coronary mesh.
To take advantage of the performance of two existing finite element codes, an iterative coupling strategy has been chosen to couple the two models based on the Dirichlet-Neumann domain decomposition method. A fixed point iterative algorithm with Aitken’s convergence has been implemented with the MPI libraries for the information exchange. The exchange variables are the average pressures on the different inlet surfaces of the ventricle mesh imposed as a boundary condition to the Navier-Stokes equations and the flow rates calculated at the different outflow surfaces of the coronary mesh imposed on the epicardial patches of the porous media.

Results: The coupling of the two codes has been verified on simple analytical tests. Then, results have been obtained on the coupling of a few larger arterial branches with the myocardium geometry. Pressure was imposed at the inlet of the coronary mesh. Hemodynamics conditions in the larger arteries were compared with and without coupling with the dowmstream porous media. The results (table 1) show that the porous media acts as a distributed resistance that modifies the distribution of flow in the various coronary branches (fig 1).

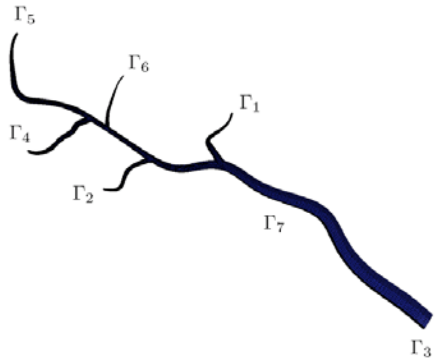

Figure 1: coronary branches

Table 1: comparison of blood flow distribution in the different coronary branches of Fig. 1 with and without coupling to the downstream porous media

	Branch without coupling	Branch with coupling
Γ_1	2.3e-4	1.7e-4
Γ_2	3.9e-4	2.0e-4
Γ_3	5.5e-5	4.7e-5
Γ_4	2.3e-4	1.6e-4
Γ_5	4.6e-4	2.2e-4

Acknowledgments: The preprocessing in the larger coronaries from the patient specific imaging data set (Zygote) was performed with the CAD softwares (3matic) and programs for surface mesh adaptation (yams2) and volume mesh generation (ghs3d).