3D MODELING OF CAROTID ARTERY AND PLAQUE PROGRESSION USING COUPLED AGENT BASED AND FINITE ELEMENT METHODS

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Introduction

It is well established that atherosclerotic plaque composition as well as its progression over time play a central role in determination of atherosclerotic plaque stability and vulnerability. This study includes an integrated approach for 3D reconstruction of patient-specific carotid bifurcation from US images and then the simulation of plaque progression using agent based modelling (ABM) and finite element modelling (FEM). The integration of different methodologies enables better understanding of atherosclerotic disease, as well as improved prediction of patients under increased risk of cardiovascular events.

Methodology

Deep learning techniques are used to segment the regions of interest including lumen and arterial wall areas, as well as plaque types. The U-Net, SegNet, and Pyramid Scene Parsing Network (PSPNet) architectures for multi-class image segmentation task have been applied. Afterwards, meshing techniques are applied to create the 3D geometry and hexagonal mesh of finite elements [1]. The characterization of carotid plaques in three dimensions could improve investigations of the changes of plaque morphology, geometry and its distribution and these can provide important information about the effects of anti-atherosclerotic therapies.

In addition, the ABM was coupled with shear stress and LDL initial distribution from the lumen. Iterative calculation inside the wall for lipid infiltration and accumulation using a random number generator for each time step has been used. The wall artery geometry has been changed which is modelled with FEM where agents from ABM are positioned inside these large finite elements. The ABM was coupled with an initial wall shear stress (WSS) profile, which triggers a pathologic vascular remodelling by perturbing the baseline cellular activity and favouring lipid infiltration and accumulation within the arterial wall. The ABM model takes shear stress and LDL initial distribution from the lumen and starts iterative calculation inside the wall for lipid infiltration and accumulation using a random number generator for each time step.

Results and Conclusions

For verification and validation of the proposed coupled methodology of ABM and FEM we used one specific patient for carotid artery model of plaque progression. The simulated model with ABM-FEM coupled model which has overall five chosen cross-sections is presented in Figure 1. The model on the left is coloured according to the distribution of total displacement of the nodes on the surface between lumen and intima. On the right, the change of the shape of the cross-sections of the arterial wall is shown in three specific moments in time (baseline, after 3 months and after 6 months).

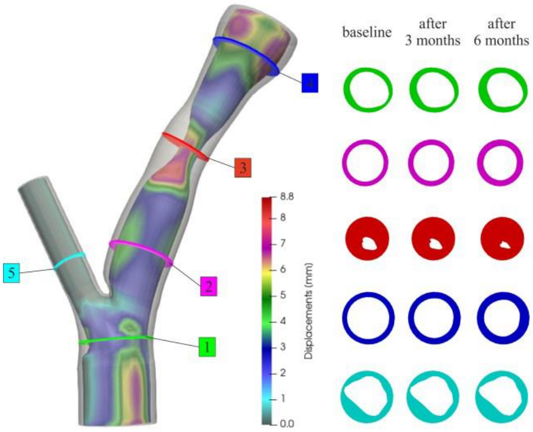

Figure 1: The results of the plaque progression simulation. The distribution of displacement of nodes of the arterial wall (left); the change of shape of chosen cross-sections over time (right).

First results show good agreement between proposed method and clinical measurements in the follow up for plaque progression. With the software presented in this study, it is possible to obtain additional information in three dimensions and perform the visualization of vascular structures in different planes from different angles [2].

References

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