CEACM S4ML 2024 CONFERENCE
19–21 June 2024, PRAGUE, CZECH REPUBLIC

SIMULATION OF PLAQUE PROGRESSION WITHIN A PATIENT-SPECIFIC CAROTID BIFURCATION RECONSTRUCTED USING A COMBINED DEEP-LEARNING APPROACH

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Note : This paper is related to the MS-3 : Modeling and Artificial Intelligence Decision Support for Bioengineering and Bio-fluids

The proper analysis of current atherosclerotic plaques and possible creation of atherosclerotic plaques on new sites inside the wall of the arteries is essential for the appropriate and timely treatment and prevention of serious ischemic cerebrovascular events. In clinical practice several non-invasive imaging techniques are applied for the diagnostics of carotid arteries, including high resolution ultrasound (US). However, during US examination, medical staff can only analyze the two-dimensional (2D) images that of the cross-sections of the analyzed artery. In this study a specific methodology that combines deep learning, mesh generation and plaque progression simulation is employed and it enables a more thorough quantitative and qualitative analysis of the state of the patient's carotid bifurcation.

Deep learning, and more precisely convolutional neural networks (CNNs) are used to segment the patient-specific US images and extract the contours of both lumen and vessel wall. In the case of the clinical dataset used within this study, two types of images were available – longitudinal and transversal images, of the three branches of the carotid bifurcation – common carotid artery (CCA), internal carotid artery (ICA) and external carotid artery (ECA). Overall a minimum of 6 images are used in the segmentation process to extract data of interest. This data is then used to create a three-dimensional (3D) model of the patient-specific carotid bifurcation and a finite element (FE) mesh. Details about the methodology applied for the reconstruction are provided in literature [1,2].

The generated FE mesh is then further used to perform a complex hemodynamic numerical simulation. The complex model applied in this study simulates not only the blood flow through the blood vessel, but also the distribution of molecules relevant for the development of atherosclerotic plaque (oxidized low-density lipoprotein (LDL), macrophages, cytokines etc.) that are transported from lumen to arterial wall and within the arterial wall itself. Details about the numerical model are provided in literature [3-5].

The results of the reconstruction process for a carotid bifurcation of one specific patient are shown in Fig. 1. The US images obtained during clinical examination are shown in Fig. 1A, Fig. 1B shows the segmented data obtained using deep learning techniques, while Fig. 1C shows the reconstructed geometry.

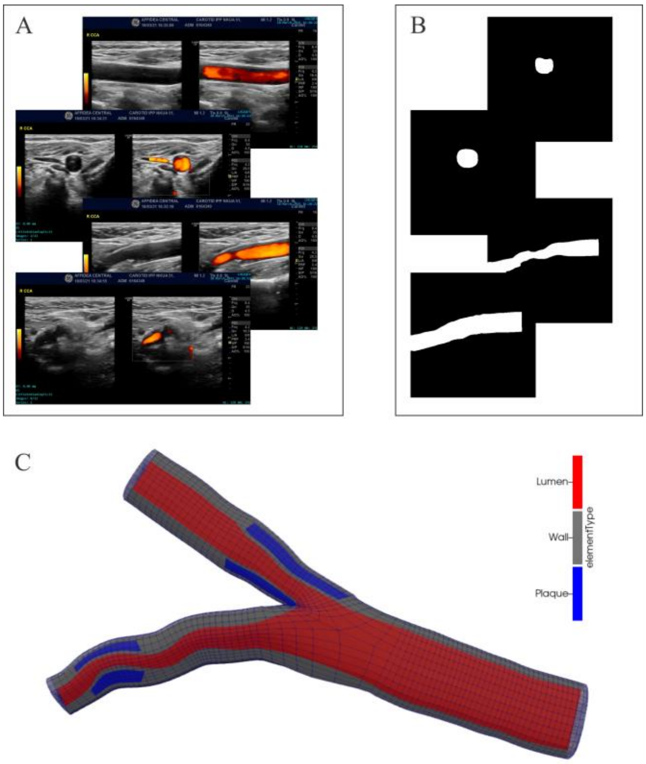

Figure 1 - The process of 3D reconstruction. A – original patient-specific US images; B – segmented lumen and wall areas using CNN; C – the reconstructed 3D FE mesh

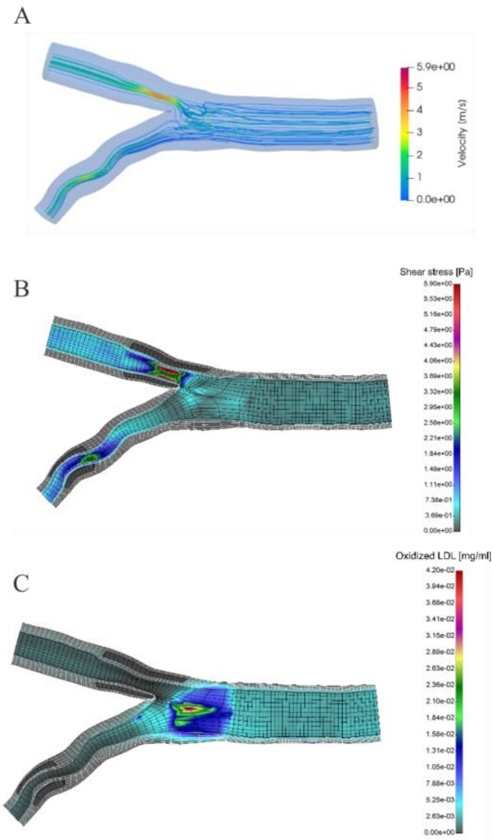

Figure 2 – Results of the numerical simulations. A – velocity streamlines; B – distribution of WSS; C – distribution of oxidized LDL

The results of the numerical simulation for this same carotid bifurcation are shown in Fig. 2. Fig. 2A shows the velocity streamlines, Fig. 2B shows the distribution of wall shear stress (WSS) on the border between lumen and arterial wall and Fig. 2C shows the distribution of oxidized LDL.

The methodology applied in this study combines the deep learning and meshing techniques to perform a patient-specific 3D reconstruction of carotid bifurcation. This data is then further applied for the numerical modeling of the process of blood flow and transport of relevant quantities through the vessel wall, and thus simulating a complex and important process in bioengineering, namely the plaque progression. This approach could provide additional information about the further growth of currently present plaque and possible sites of further occurrences, which could be very beneficial to better estimate possible risks and ensure patient-specific treatment planning.

Funding

This research has received funding from the European Union’s Horizon Europe research and innovation programme under Grant Agreement Numbers 755320-2 – TAXINOMISIS, 952603 – SGABU and 101080905, funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or granting authority - European Health and Digital Executive Agency (HADEA). Neither the European Union nor the granting authority can be held responsible for them. This research is also part of the project of multilateral collaboration in the Danube region, No. 337-00-140/2023-05/05 titled “Synergy of multiscale Modelling and machine Learning: Strategy for biomedical sciences and battle against cancer”. This research is also funded by the Serbian Ministry of Education, Science, and Technological Development [451-03-47/2023-01/200378 (Institute for Information Technologies, University of Kragujevac) and 451-03-47/2023-01/200107 (Faculty of Engineering, University of Kragujevac)].

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