70TH ESCVS CONGRESS
& 7TH IMAD MEETING
20 I 23 JUNE 2022

AGENT BASED AND FINITE ELEMENT METHOD FOR PLAQUE DEVELOPMENT IN THE CAROTID ARTERY

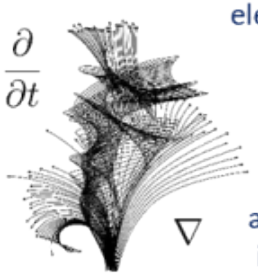
Nenad Filipovic[a,b], Andjela Blagojevic[a,b], Smiljana Tomasevic[a,b], Branko Arsic[b], Tijana Djukic[b]
[a]Faculty of Engineering University of Kragujevac, Kragujevac, Serbia, fica@kg.ac.rs
[b]BioIRC Bioengineering Research and Development center, Kragujevac, Serbia, smiljana@kg.ac.rs

20-23 June 2022
Liege, Belgium

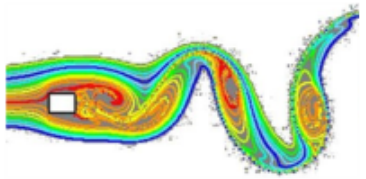
FEM AND ABM CONCEPT

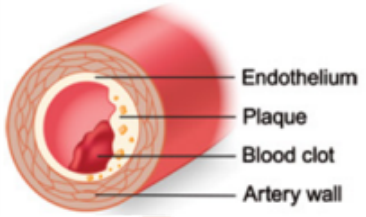
FEM is a computational method for problems whose **overall** behavior can be explained by **partial differential equations**. Such equations are generally useful when the problem scale is bigger than the scale of its elements.

$$\frac{\partial}{\partial t} \quad \nabla$$



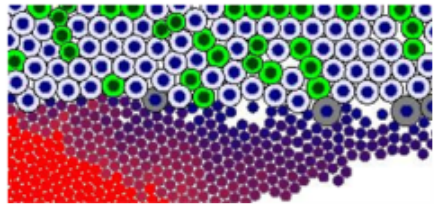
It is a continuum approach and **ignores individual elements reactions** and only catches their gross effect.





A **multicellular biological system** including several physio/bio-logical processes: lipoproteins transport, hemodynamics, macrophage, foam cells and plaque development, etc.

The dynamics of these processes is strongly dependent on the **discrete nature** of the **interactions** between cells, molecular/bio-markers, pharmacodynamics and pharmacokinetics.



ABMS can be instead considered as a **cell-based** approach where **individual physio/bio-logical processes** are modelled at the cellular scale based on a set of "rules".

Therefore **ABMS** accommodates better, with respect to FEM, the high level of **complexity** of the present multicellular biological system, and also allows to integrate the different **mechanisms** affecting **plaque progression**.

DEVELOPMENT OF ABM

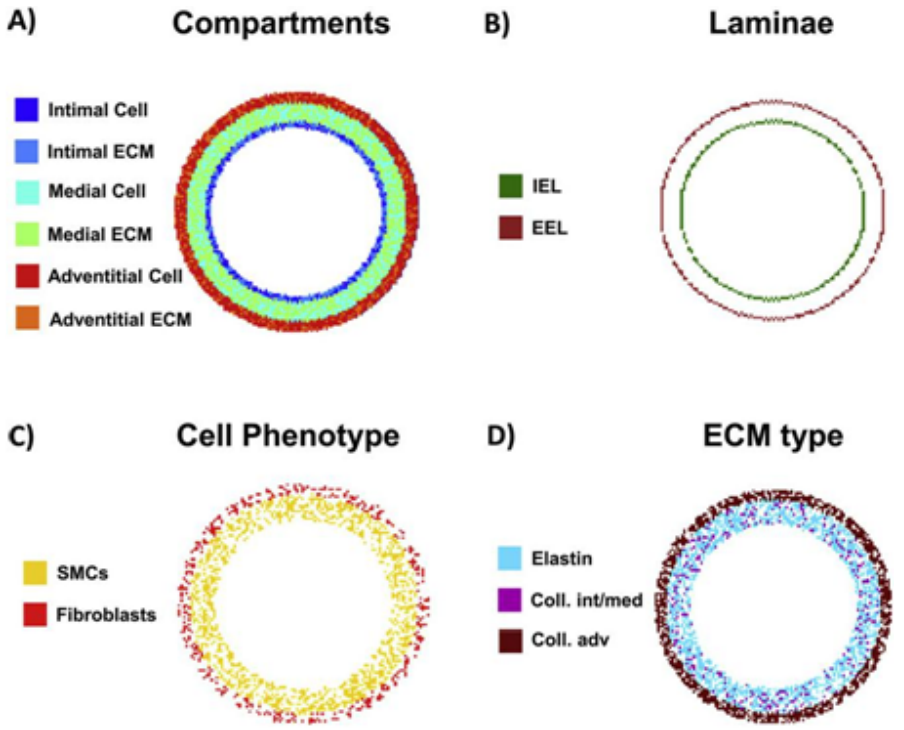
The development of ABM is inspired by the model developed by Corti et al. [1]

- **Initialization**

The initial geometry was a 2D circular cross-section composed by 3 concentric layers - tunica intima, media and adventitia **(A)** with the internal and external elastic laminae - IEL and EEL **(B)**.

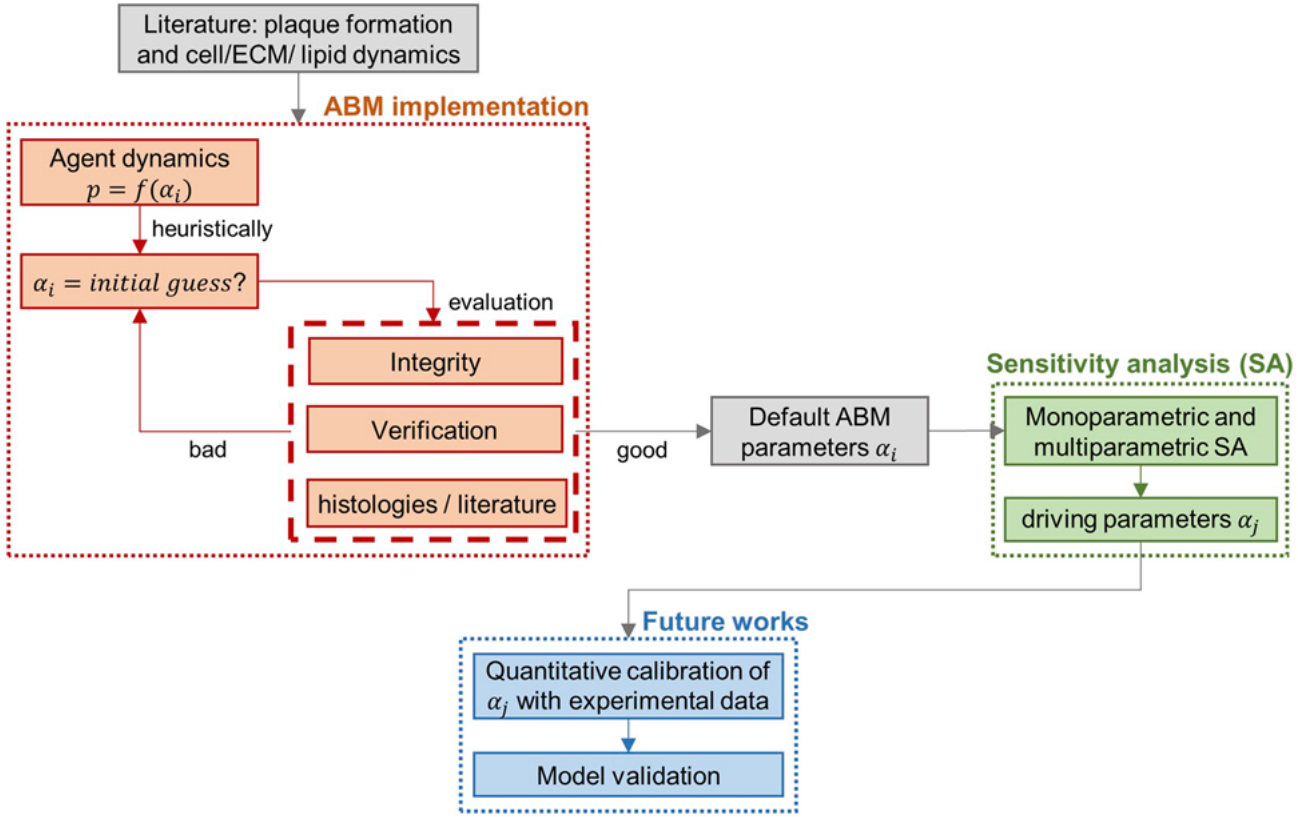
C) Cellular composition of the arterial wall, with Smooth Muscle Cells (SMCs) in the intima and media layers and fibroblasts in the adventitia layer.

D) ECM composition of the arterial wall, with elastin and collagen in the intima and media layers and collagen in the adventitia layer.



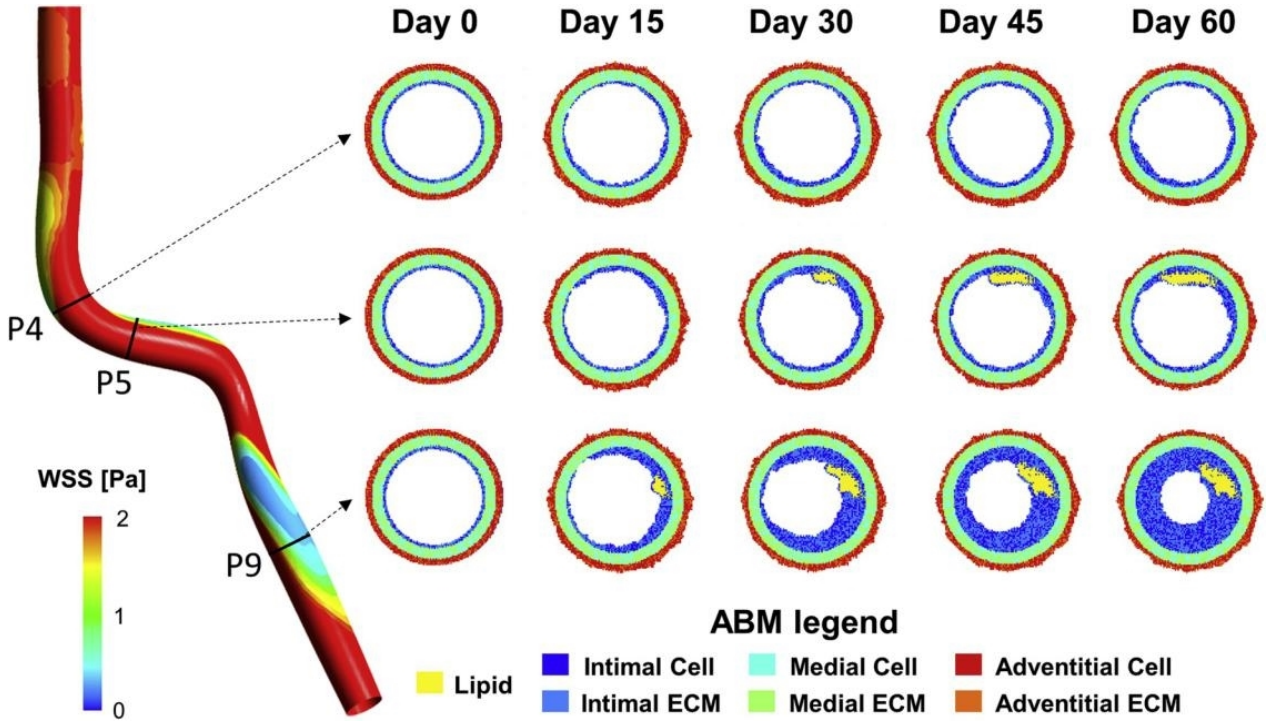
[1] Corti, A., Chiastra, C., Colombo, M., Garbey, M., Migliavacca, F., & Casarin, S. (2020). A fully coupled computational fluid dynamics–agent-based model of atherosclerotic plaque development: multiscale modeling framework and parameter sensitivity analysis. *Computers in biology and medicine*, 118, 103623.

THE WORKFLOW ADOPTED FOR THE IMPLEMENTATION OF THE AGENT DYNAMICS AND THE PARAMETER SETTINGS



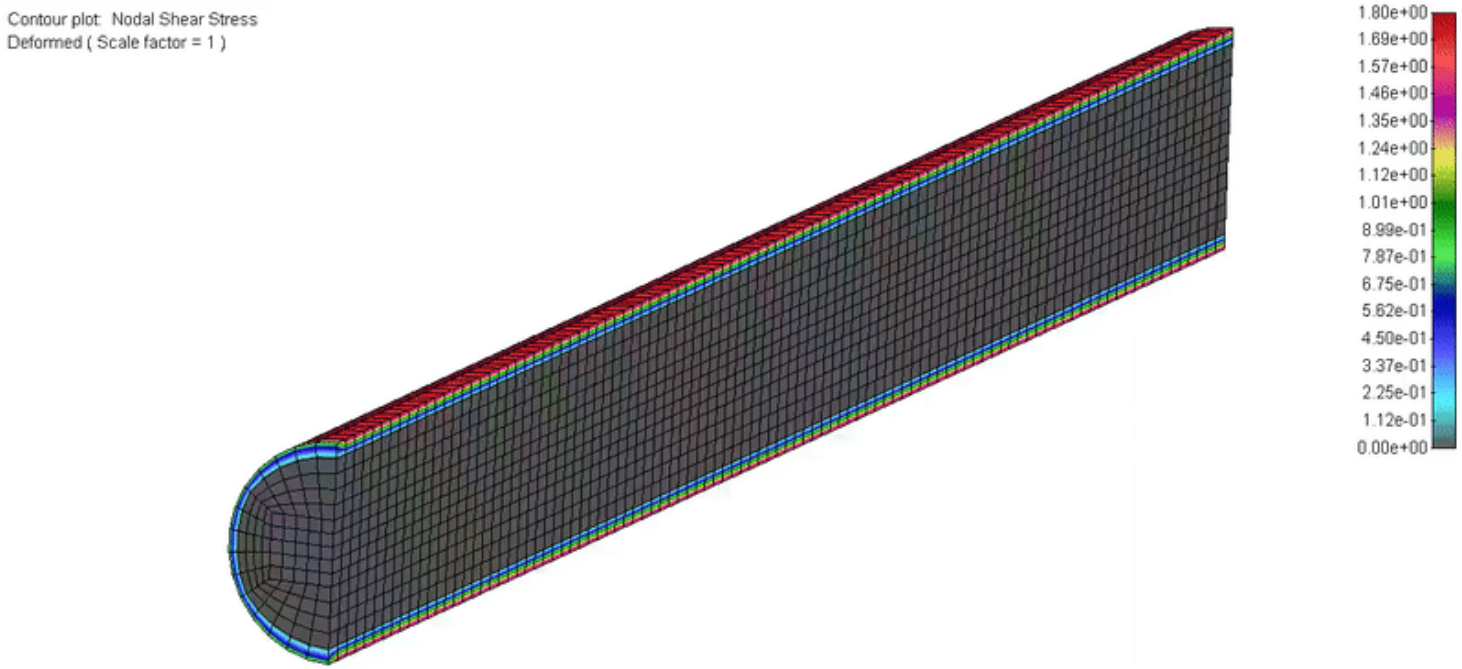
SENSITIVITY ANALYSIS

Agent-Based Model (ABM) sensitivity to Wall Shear Stress (WSS). On the left, the initial WSS contour, on the right, the 2-months ABM-simulated process of wall remodelling for planes 4, 5 and 9. For each plane the most representative simulation output out of ten is selected and five intermediate cross-sections are provided with a 15 days time-step.



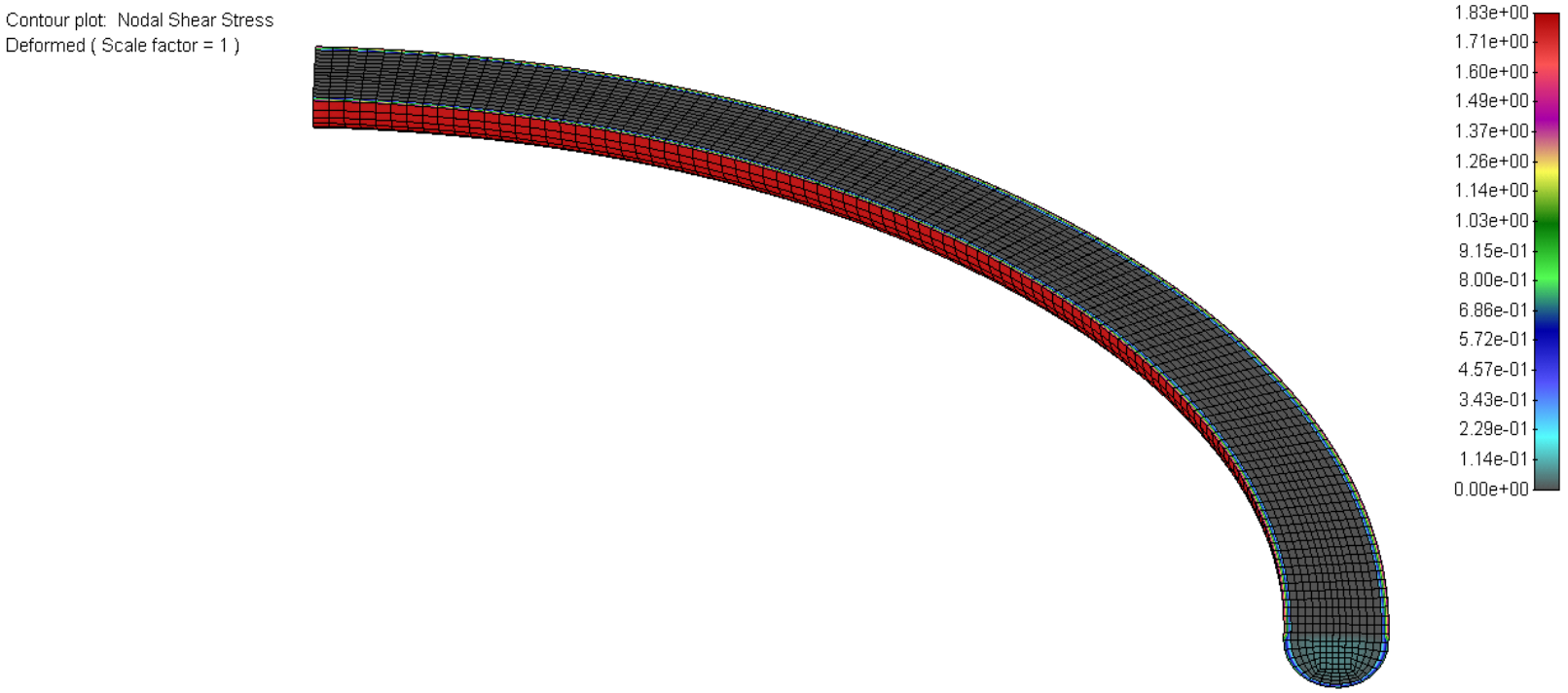
COUPLED FE AND ABM

- Blood flow through a straight blood vessel with stenosis was modeled using finite element method.
- Fluid dynamics computation is performed by PAKF FE solver, giving velocity and pressure field, as well as wall shear stress distribution.
- ABM method was applied on the arterial wall taken into account cell mitosis and ECM production in the intima including lipid cells.



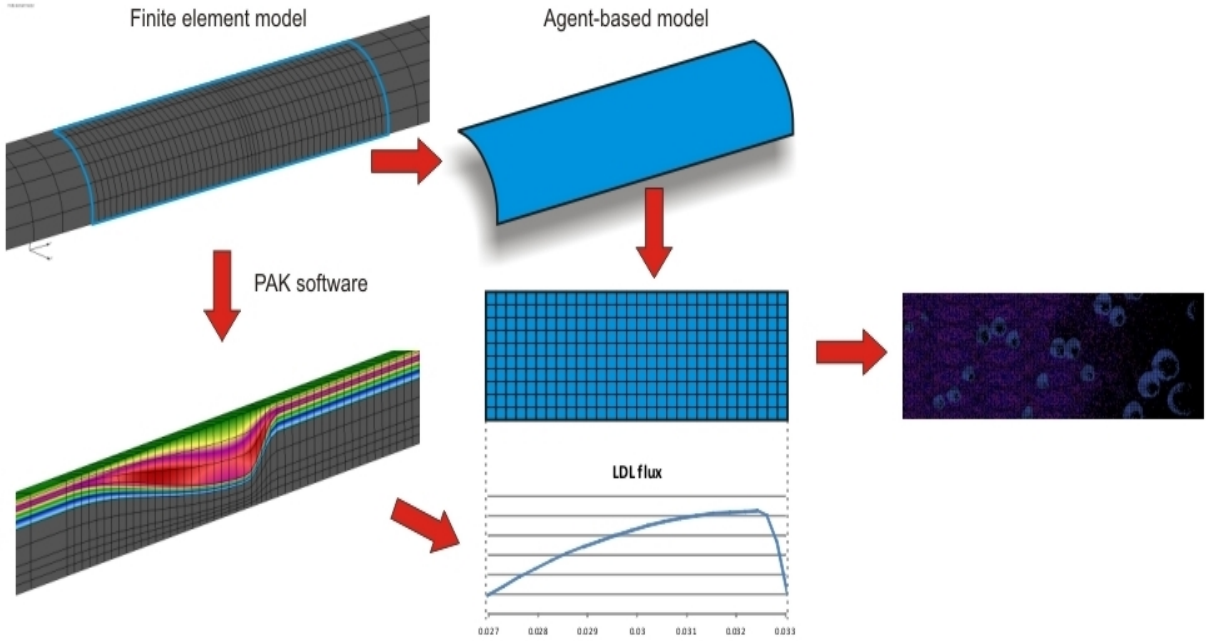
COUPLED FE AND ABM

- Blood flow through a curve blood vessel with stenosis was modeled using finite element method.
- Fluid dynamics computation is performed by PAKF FE solver, giving velocity and pressure field, as well as wall shear stress distribution.
  - ABM method was applied on the arterial wall taken into account cell mitosis and ECM production in the intima including lipid cells.



COUPLED FE AND ABM

- The process of atherosclerosis development inside blood vessel wall is modeled using the ABM, where an unfolded wall cylinder is taken as the domain of interest.
- The whole domain area is divided into grid of cells (spots) where agents interact. Size of spots is chosen so that each spot can accept only one macrophage, one of the key actors in atherosclerosis process.



EXAMPLE FOR CAROTID ARTERY PLAQUE PROGRESSION