Dottorato di ricerca in Ingegneria Biomedica e Informatica
Dipartimento di Medicina Sperimentale e Clinica
Università Magna Græcia di Catanzaro
Campus di Germaneto- Viale Europa - 88100 CATANZARO

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Mathematical Model of Blood Flow in Carotid Bifurcation

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Research's goal

The goal of this research is to provide the medical staff a numerical system assessment of wall shear stress in carotid bifurcation.

Added value of the research project

Through this model, it will be fundamental to investigate the stress state properties of the surface in contact between the plaque and the artery, and study the geometric relationship between the bifurcation angle and fluid structural properties.

Analysis of patology

Stroke constitutes the third most frequent cause of death and a leading cause of long-term disability in developed countries; in about 80% of cases, stroke is an ischemic disease.

Nature of ischemic stroke is linked to the characteristic itself of the atherosclerotic process that is the cause of the disease almost in half of the patients.

Carotid atherosclerosis is locally favoured by the hemodynamic forces of wall shear stress and circumferential wall tension, the frictional and perpendicular force of blood flowing on the vascular wall respectively.

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Boundary conditions for Fluid dynamics analysis

The first part of the study aims to verify the numerical consistence of fluid dynamic comsol model based on Navier-Stokes equations in transient regime. A fluid dynamic analysis for the vessel is performed to compute the velocity at different time instances.

Blood flows under the influence of pulsating pressure is defined as a time varying function:

$$f(t) = \begin{cases} \sin \pi t & 0 \le t \le \frac{1}{2} s \\ \frac{3}{2} - \frac{1}{2}\cos(2\pi(t - \frac{1}{2})) & \frac{1}{2} \le t \le \frac{3}{2} s \end{cases}$$

Navier Stokes equation for Fluid dynamics analysis :

$$\rho \frac{\partial u}{\partial t} + \rho u \nabla u = -\nabla P + \eta \nabla^2 u + F$$

$$\nabla u = 0$$

Where:
ρ denotes density (*kg/m3*)
u velocity vector (*m/s*);
η viscosity (*Ns/m2*) and *P* pressure (*Pa*).

Boundary conditions:

- viscosity 0.005 *Pa/s* and density 960 *kg/m3*;
- medium systolic pression at the entrance and outlet of the arthery (*Pin* and *Pout*).
- other boundaries have a no-slip condition *u=0*.

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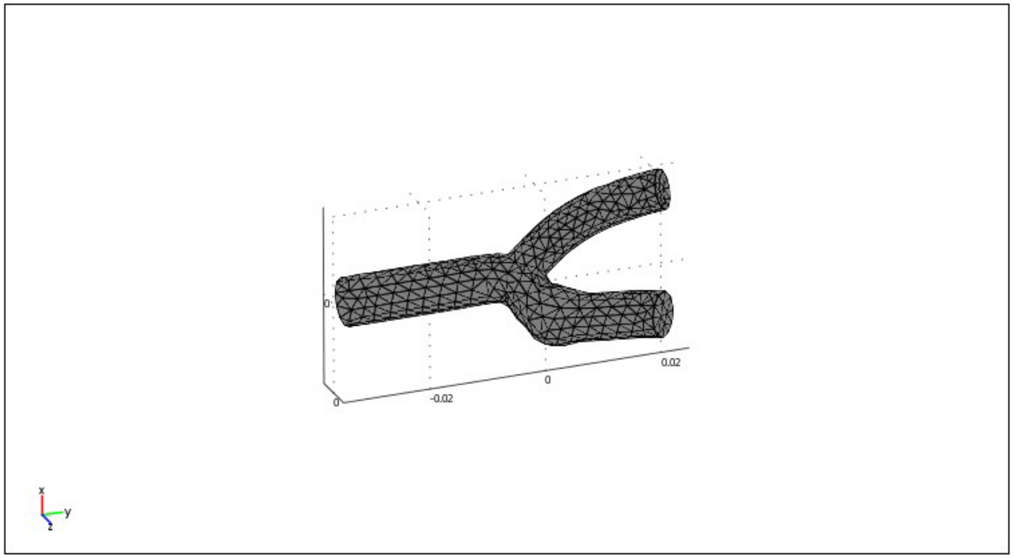
Mesh parameters for Fluid dynamics analysis :

The model was meshed with different densities for the individual sub-domains. The mesh for artery enables us to solve for degrees of freedom. The parameters are described in table:

Number of elements	8344
Number of boundary elements	3760
Number of edge elements	280
Minum element of quality	0.22



Solver: Direct UMFPACK

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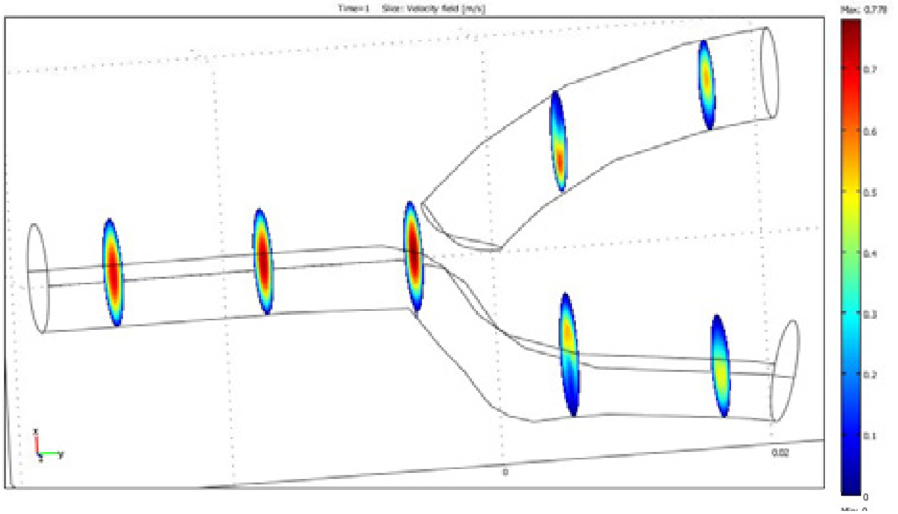
Postprocessing: Laminar Flow

- Field of Velocity

Numerical velocity=30cm/sec;

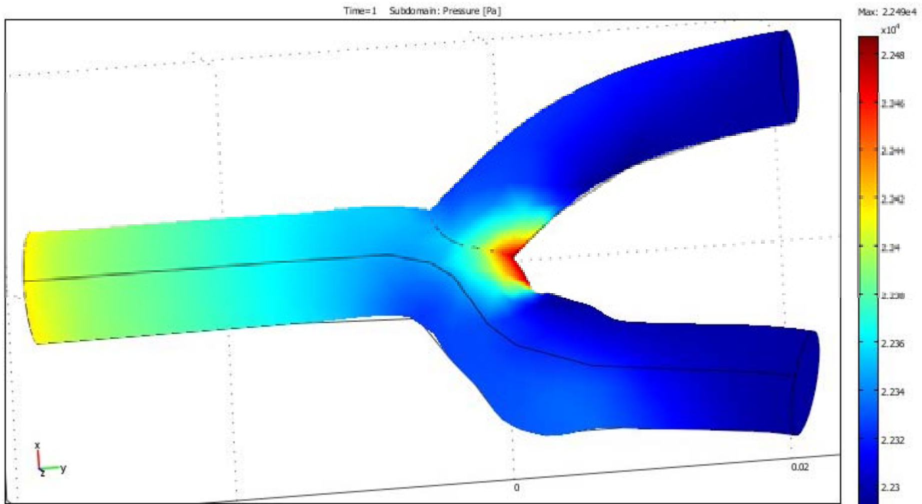
Medium experimental velocity:35 cm/sec



- Field of Pressure:

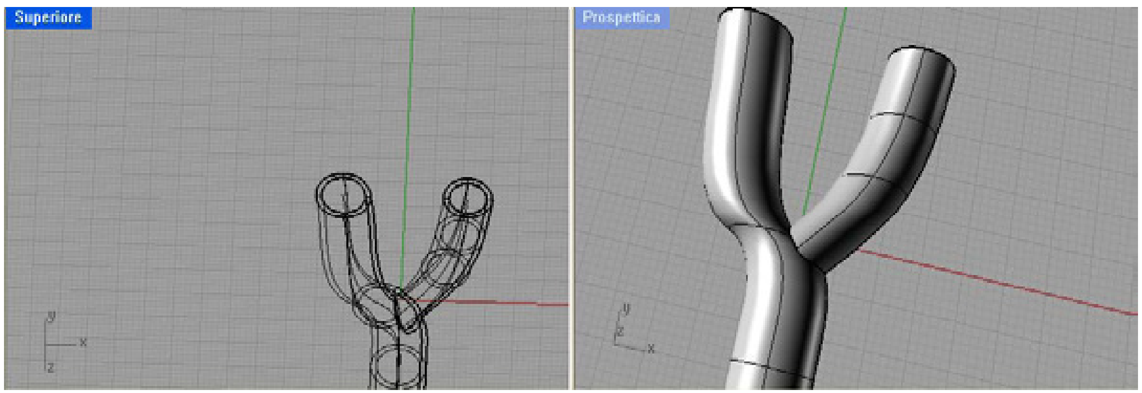
Medium Max Numerical pressure: 90 mmHg

Medium Max Experimental pressure: 110 mmHg



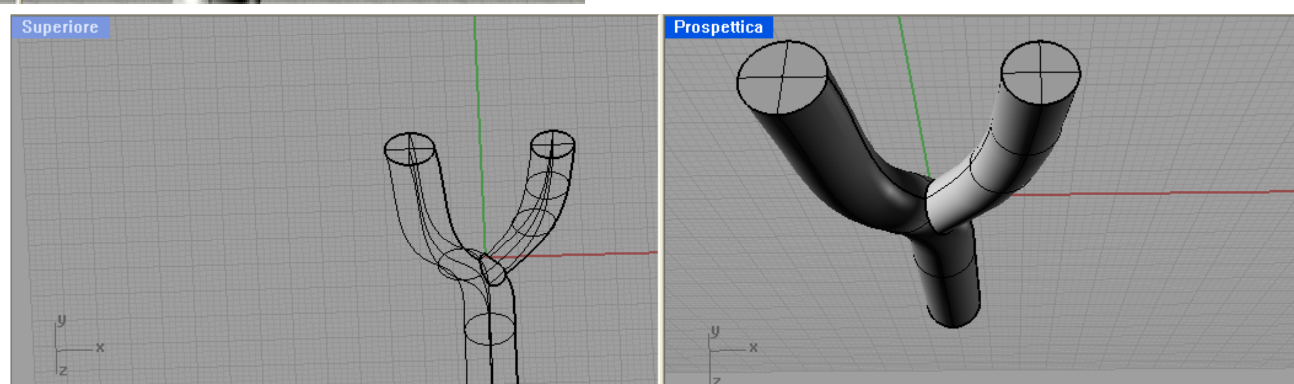
Fluid-Structure interaction mechanical module in Comsol

A mechanical analysis was performed by the StructuralMechanics module. The two models are interconnected to each other by boundary conditions, as the normal component of the surface force provides the coupling between them.



← Arthery

Blood →



Boundary condition in interaction fluid-structure

rho_blood	1060 [kg/m^3]	blood density
eta_blood	0.005[Pa*s]	blood viscosity
p_out	11148 [N/m^2]	Outlet pressure
v_in	0.3 [m/s]	inlet pressure
rho_artery	960[kg/m^3]	density of arthery
m_artery	6204106[Pa]	Neo-Hookean hyperelastic behavior, mu coefficient for artery
v_artery	20*m_artery	Bulk modulus for artery
vincolo	10000[N/m^3]	Muscolar rigidity
Hyperelastic Model	Neo-Hookean	
Initial shear module	m_artery	
Initial bulk module	v_artery	

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Boundary condition in interaction fluid-structure

The structural deformations are solved by using an elastic formulation and a nonlinear geometry formulation to allow large deformations.

A load from the fluid is given by a sum of pressure and viscous forces

We have used experimental dates to describe the distribution of rigidities on external boundaries in these equation form:

$$Fx = -k * u;$$

$$Fy = -k * v;$$

$$Fz = -k * w;$$

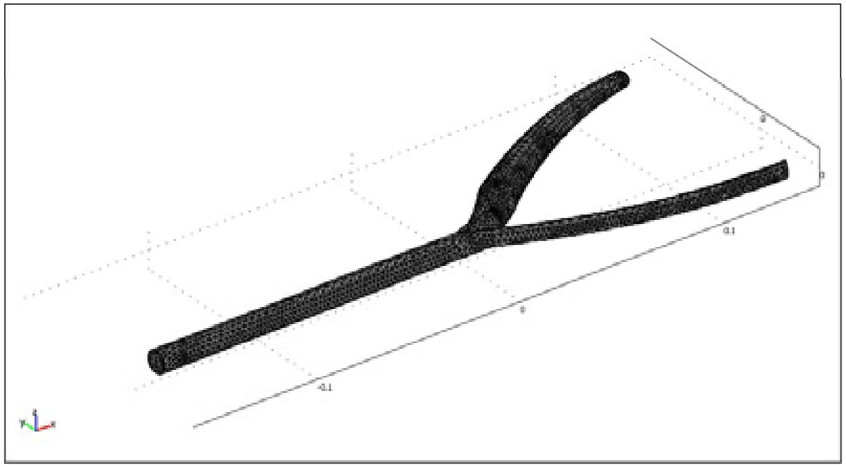
Mesh parameters

The model was meshed with different densities for the individual sub-domains. The mesh for artery enables us to solve for 90119 degrees of freedom.

Method mesh:Triangle;

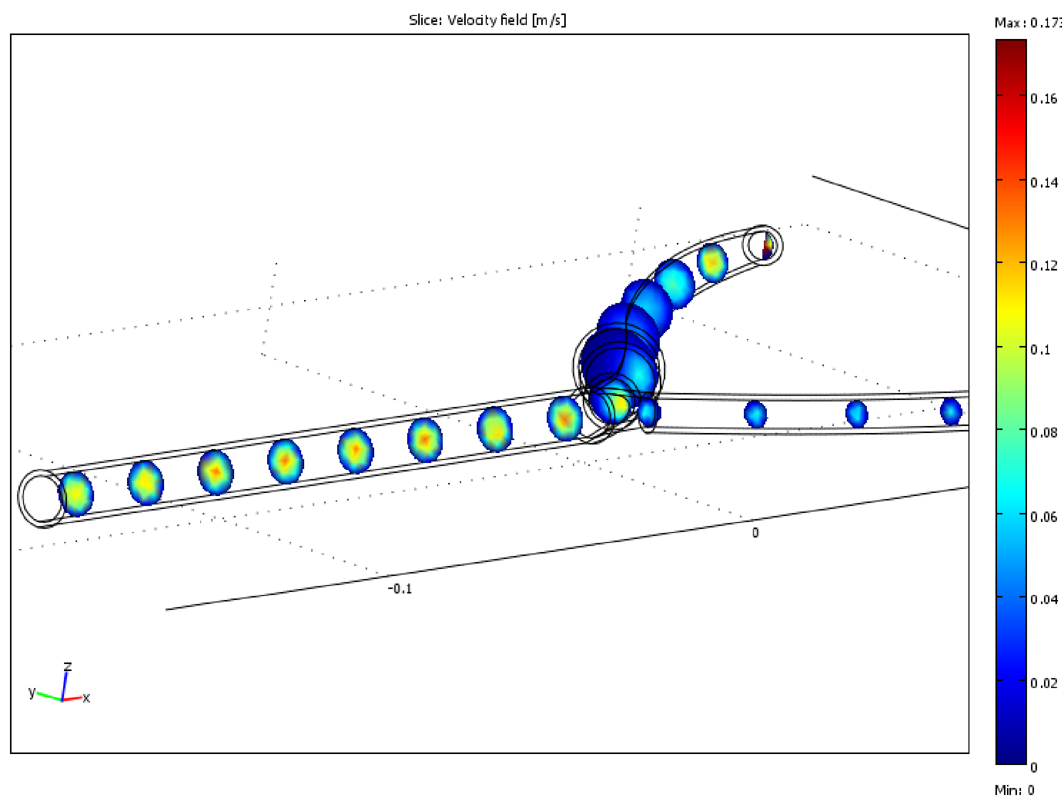
Predefined mesh: Normal;

Number of elements	45000
Number of boundary elements	17940
Number of edge elements	1000



Postprocessing: Field of Velocity

- Laminar flow in common arthery
- Numerical velocity in common arthery: 20 cm/s
- Experimental velocity in common arthery: 35 cm/s



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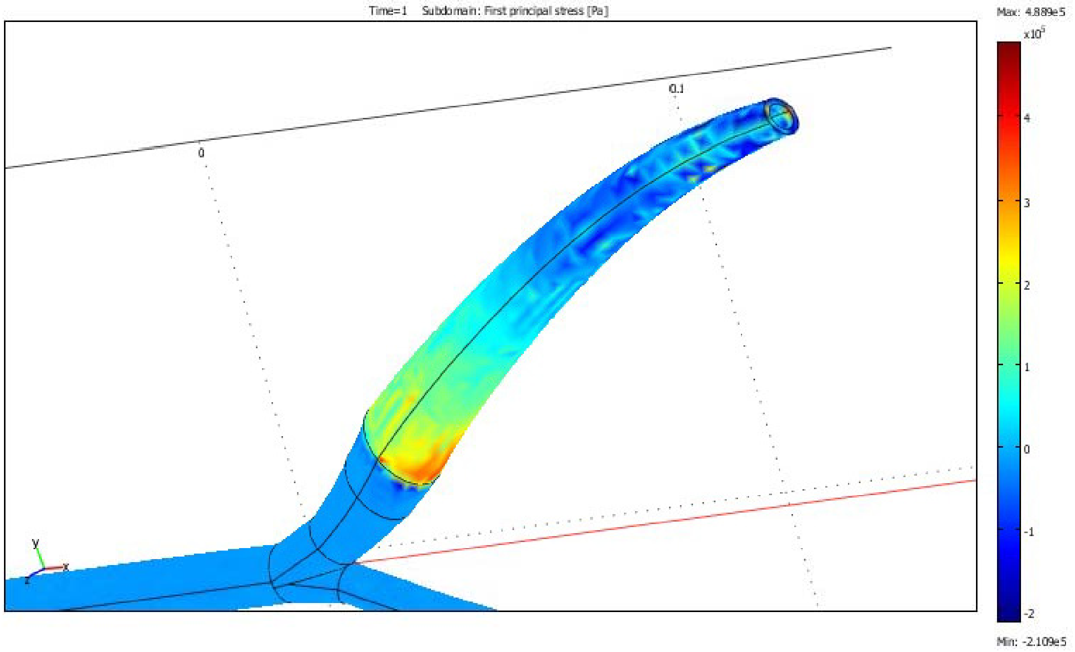
Postprocessing: First Principal Numerical Stress

- Experimental medium First Principal distribution: 250 kPa
- Numerical medium First Principal distribution: 230 kPa



Next phase: The theory of k-ε in chemical engineering module

The next phase is to introduce turbolence scale inside model to riproduce the experimental flow inside biforcation

- Turbolent lenght scale:0.8;
- Re=10000;
- Field of velocity in the direction of flow 50 cm/sec;
- Pressure in output: 11148 kPa;
- Turbolence intencity: 0.05

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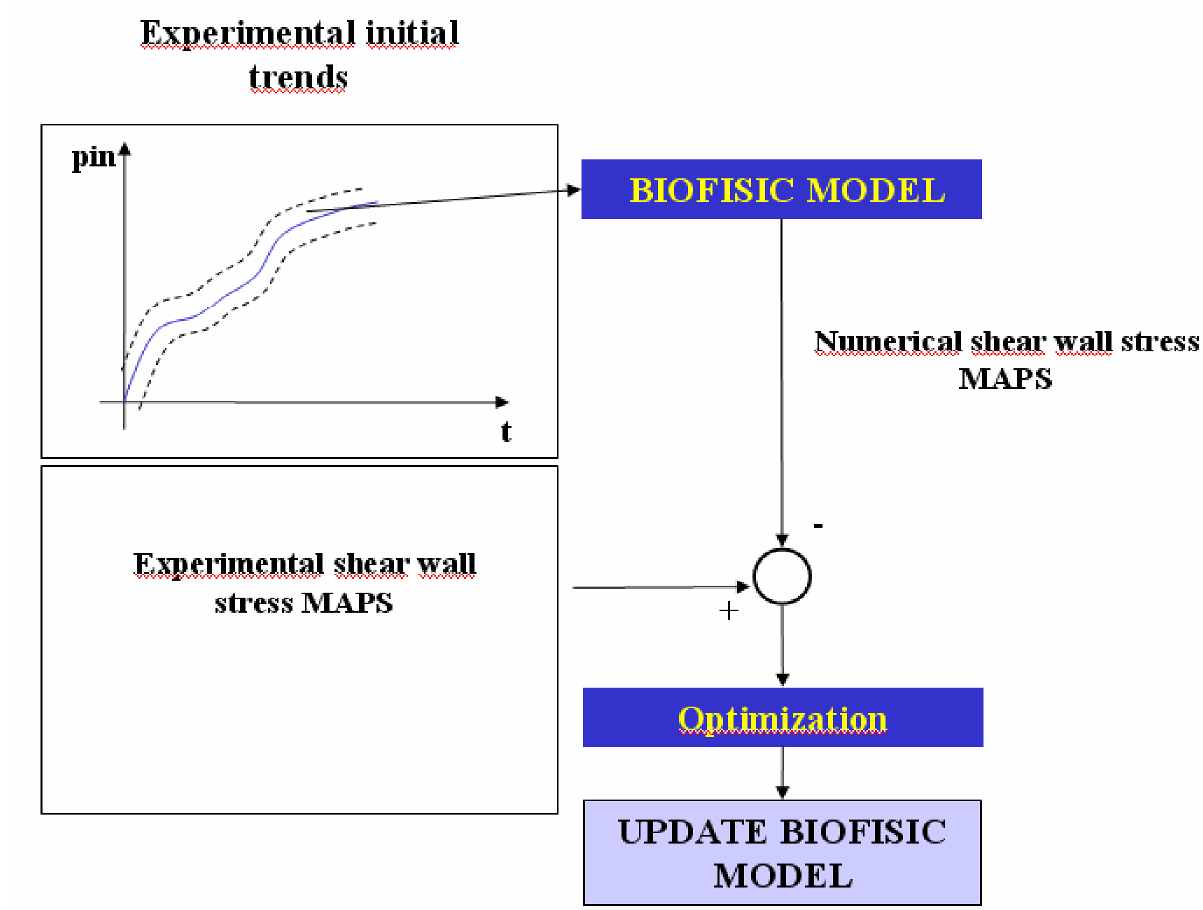
The actual target

A method based on a tool of optimization to find some appropriate weights by the comparison with experimental analysis. By working on some mechanical units such as material stiffness we want to correct the numerical model.



Conclusion

This model can be seen as a mean to predict:

- Fluid-structural conditions that would appear in human carotid bifurcation after surgical procedure;
- The wall shear stress in presence of stenosis in internal arthery through the experimental reading of biodinamic parameters supplied by Doppler read in common arthery.