Numerical simulation of blood flow in LAD models with different degrees and location of stenosis.

Konstantinos Papadopoulos,
Mitroglou Nicholas
and Gavaises Manolis

***S**chool of **E**ngineering and*
***M**athematical **S**ciences*

CITY UNIVERSITY LONDON

1. Outline

- **Solution:**
  - **Description of the problem**
  - **Case setup**
  - **Results**

- **Pre and Post processing:**
  - **ANSA & Python scripts for geometry modification**
  - **μETA and BETA scripts for result processing**

Coronary Artery Disease (CAD)

- CAD is the formation of plaques on the walls of Coronary artery (CA)
- Complications: Angina, Myocardial infarction
- World's leading cause of death

Blocked CA with subsequent thrombus formation

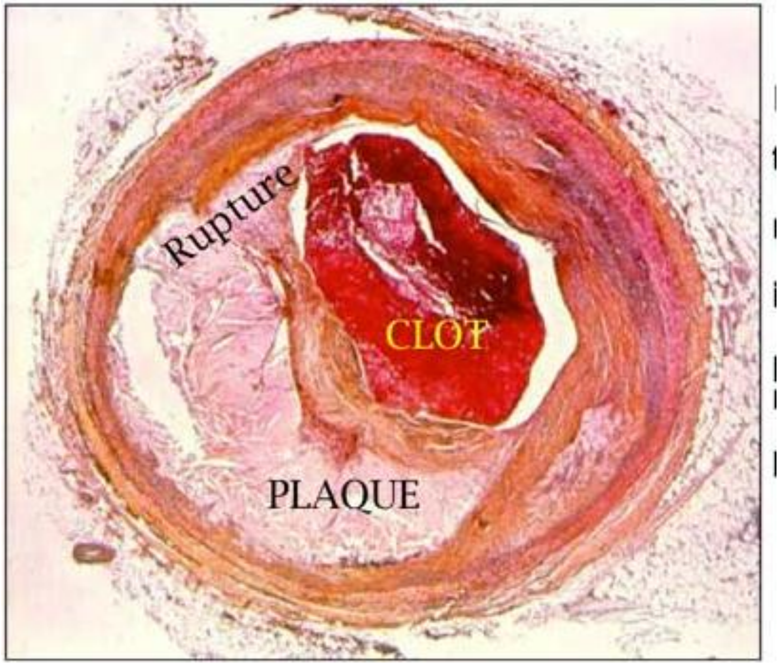
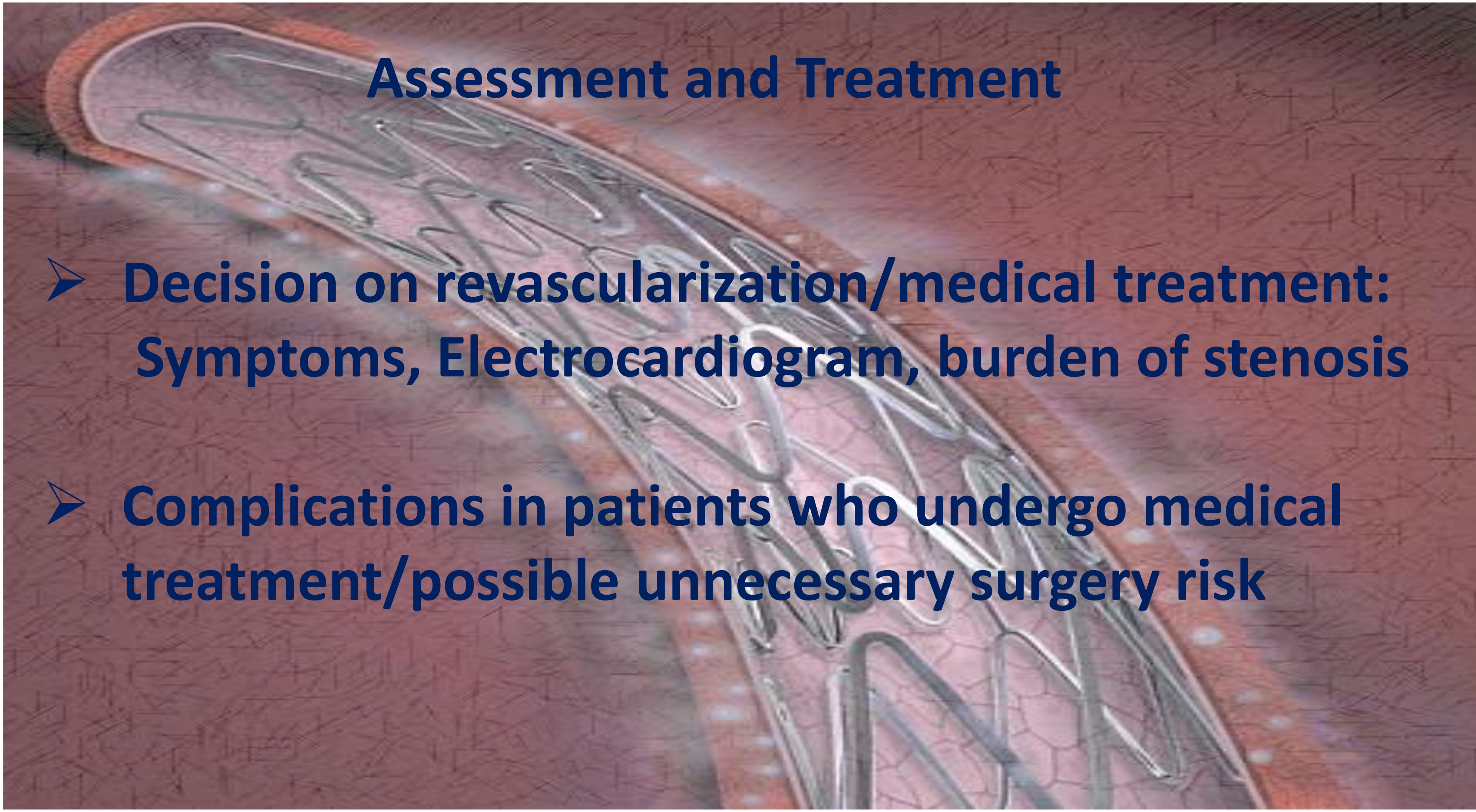


Image: Panaceia or Hygeia- Atherosclerosis http://medicalmyths.wordpress.com/atherosclerosis/



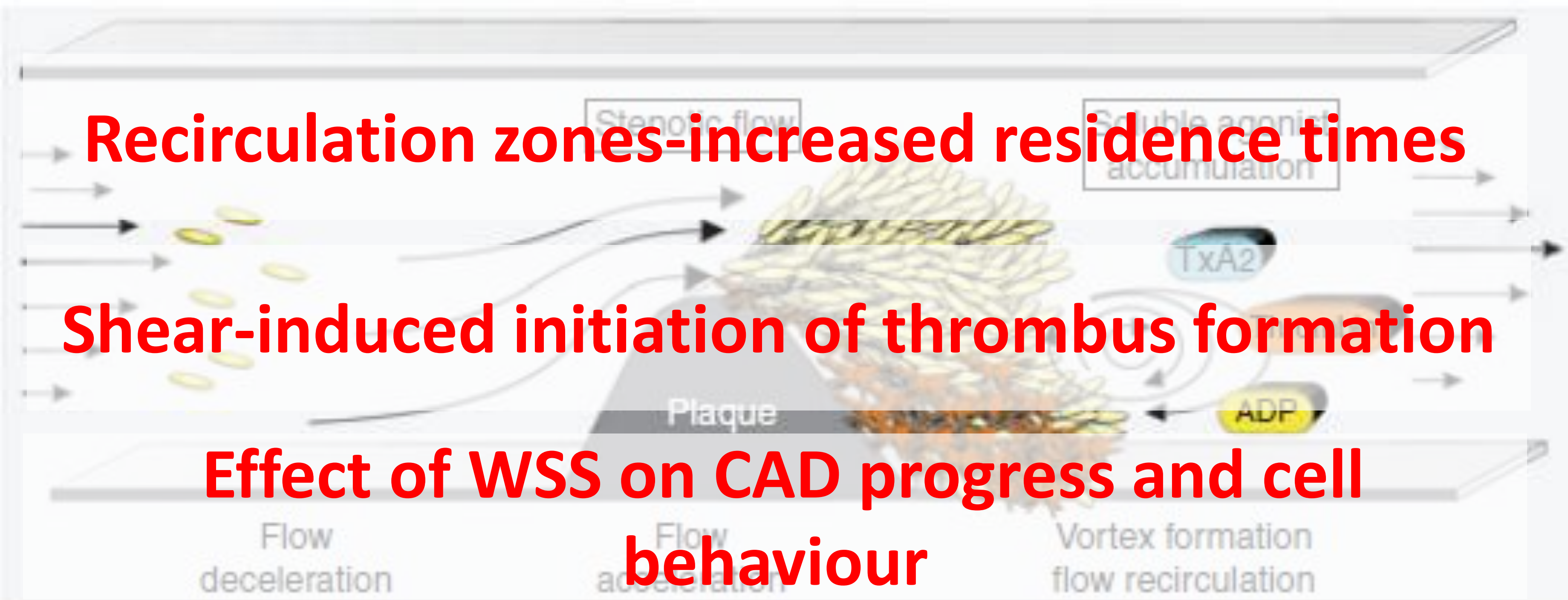
Assessment and Treatment

- **Decision on revascularization/medical treatment: Symptoms, Electrocardiogram, burden of stenosis**
- **Complications in patients who undergo medical treatment/possible unnecessary surgery risk**

Image: Encyclopedia Britannica

Impact of flow

Statistical correlation between location of stenosis and complications-Physical mechanisms



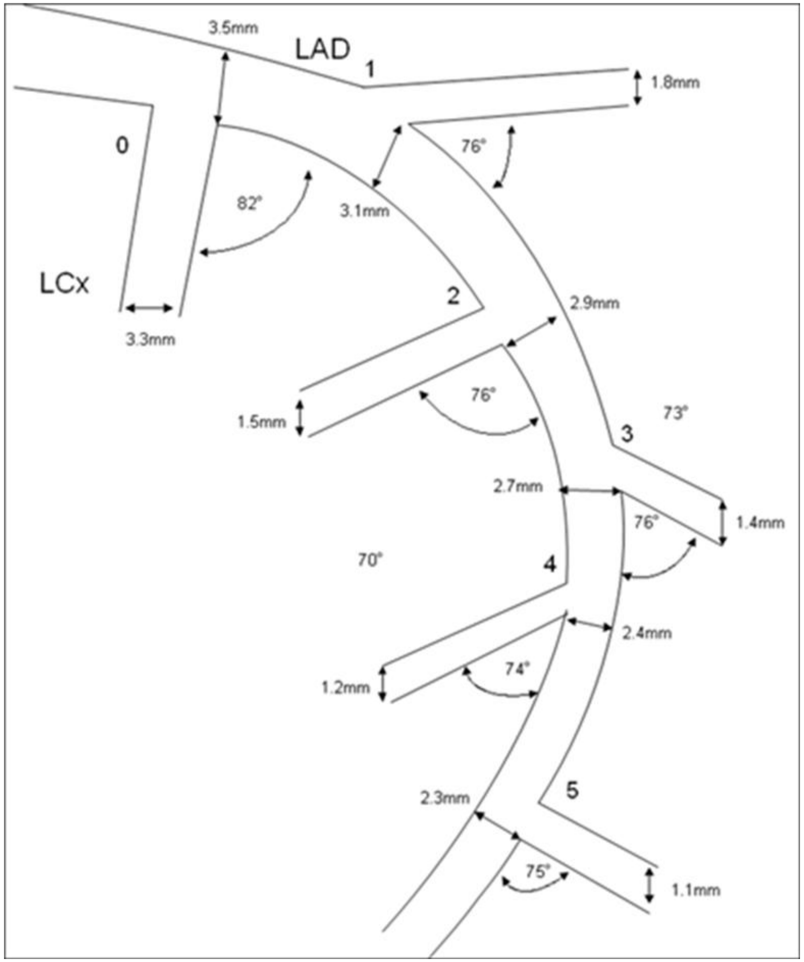
Recirculation zones-increased residence times

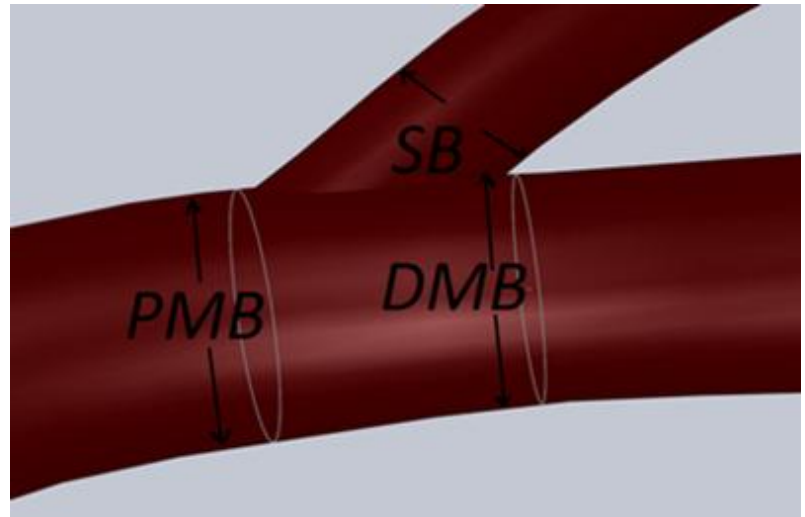
Shear-induced initiation of thrombus formation

Effect of WSS on CAD progress and cell behaviour

Image: Jackson et al 2009 , Dynamics of platelet thrombus formation

Geometry reconstruction





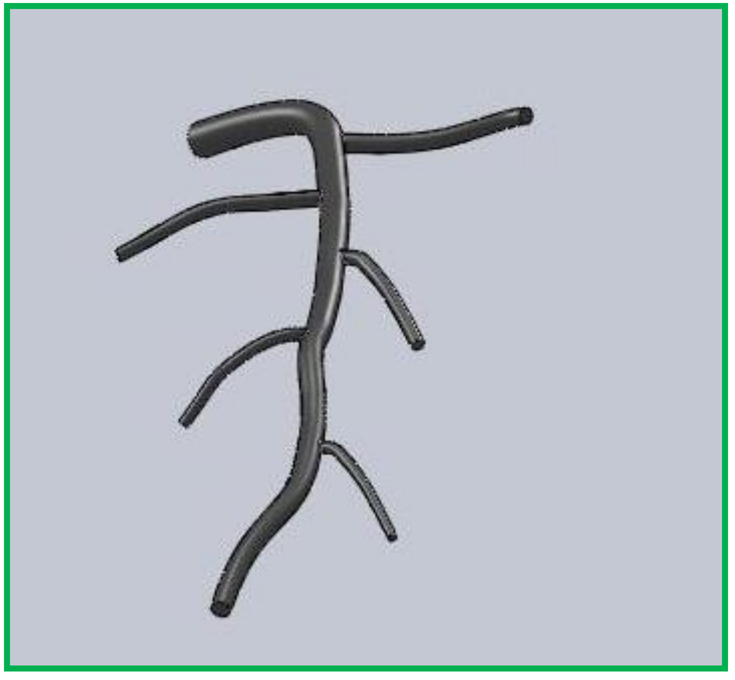
Construction of an averaged LAD geometry based on statistical data. Tapering based on the formula

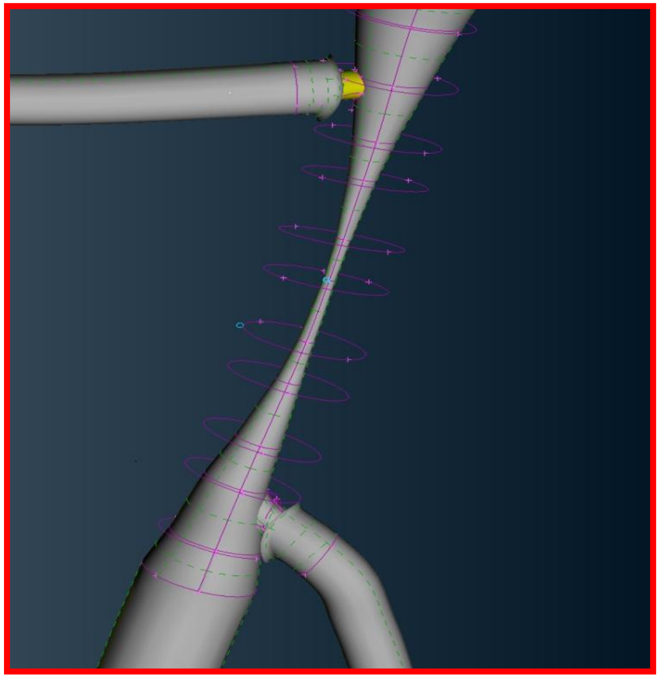
$$PMB = (DMB + SB) \times 0.678$$

Healthy and stenosed geometries

Normal geometry designed in Solidworks

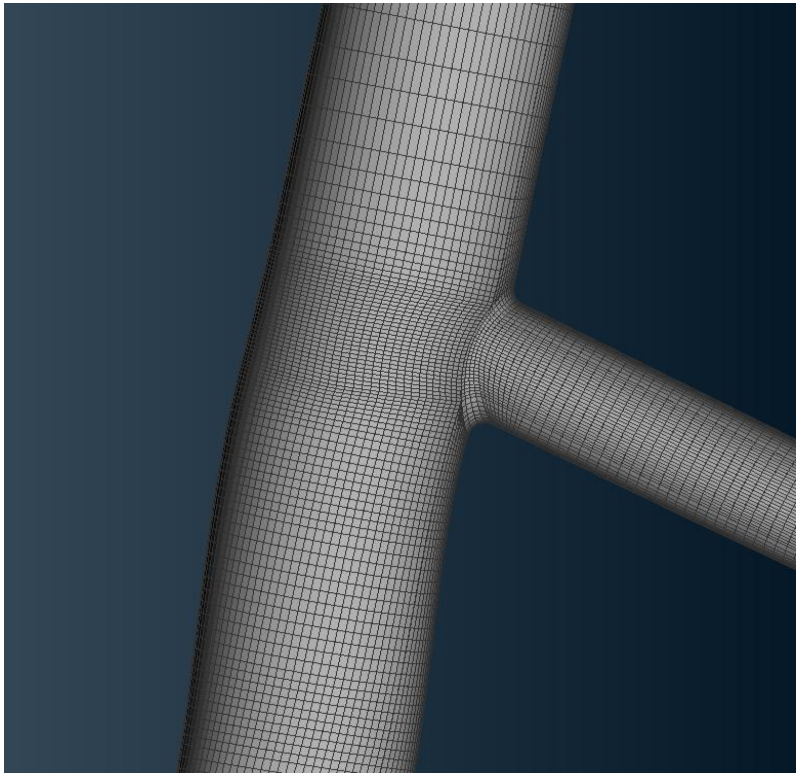
Geometries with maximum stenosis (90%) designed in ANSA by introducing sinusoidal reduction of vessel diameter around the center of the stenotic lesion.

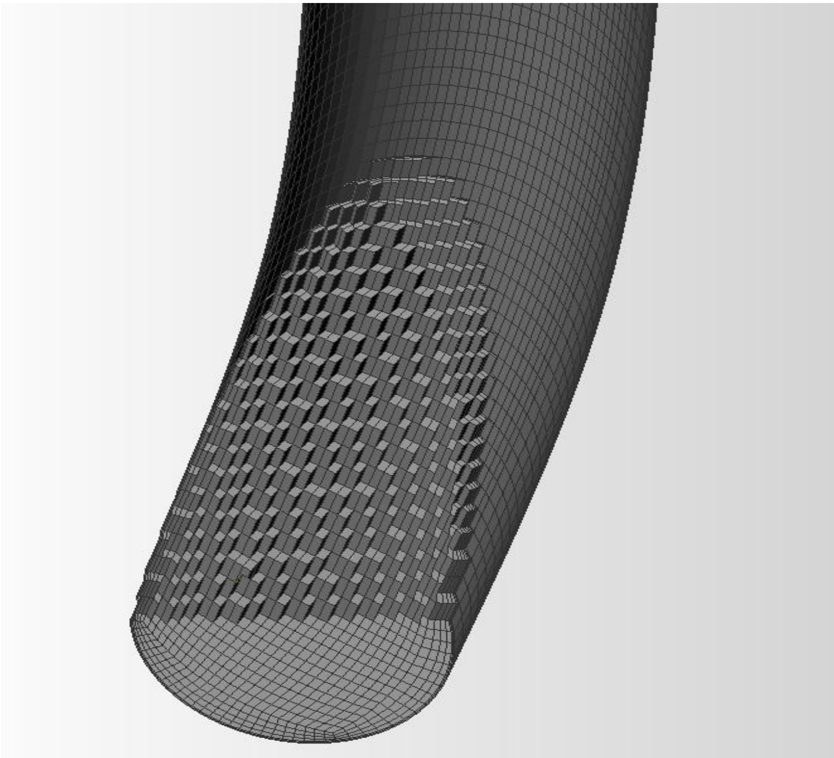




Pure Hexa-block Grid

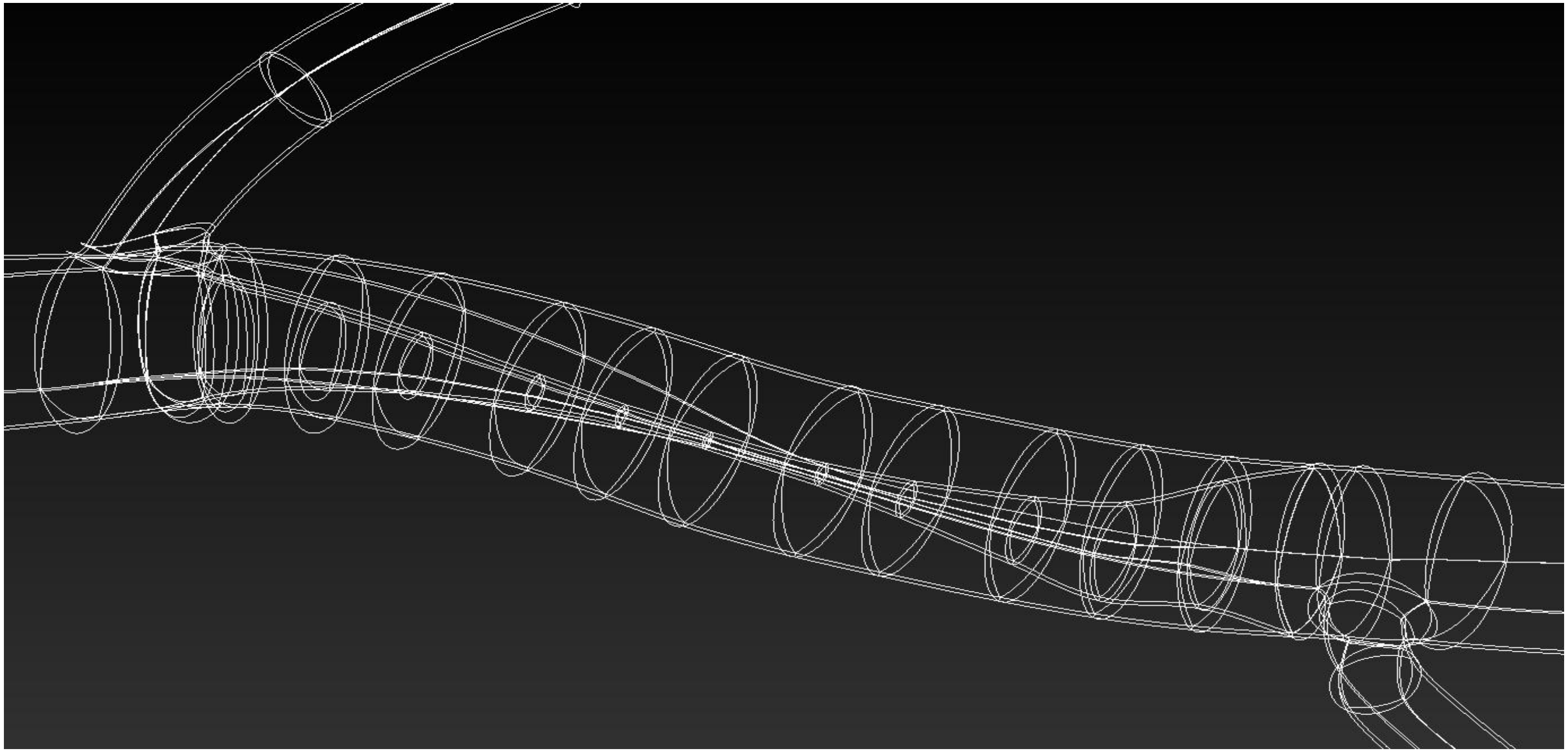
Hexablock mesh with boundary layers for normal geometry and geometries with maximum stenosis (90%)





Hexa-block boxes

Identical mesh (nodes and ids) for normal and geometries with maximum stenosis



Construction of intermediate models

Normal model (no stenosis)

+

Model with maximum (90%) stenosis

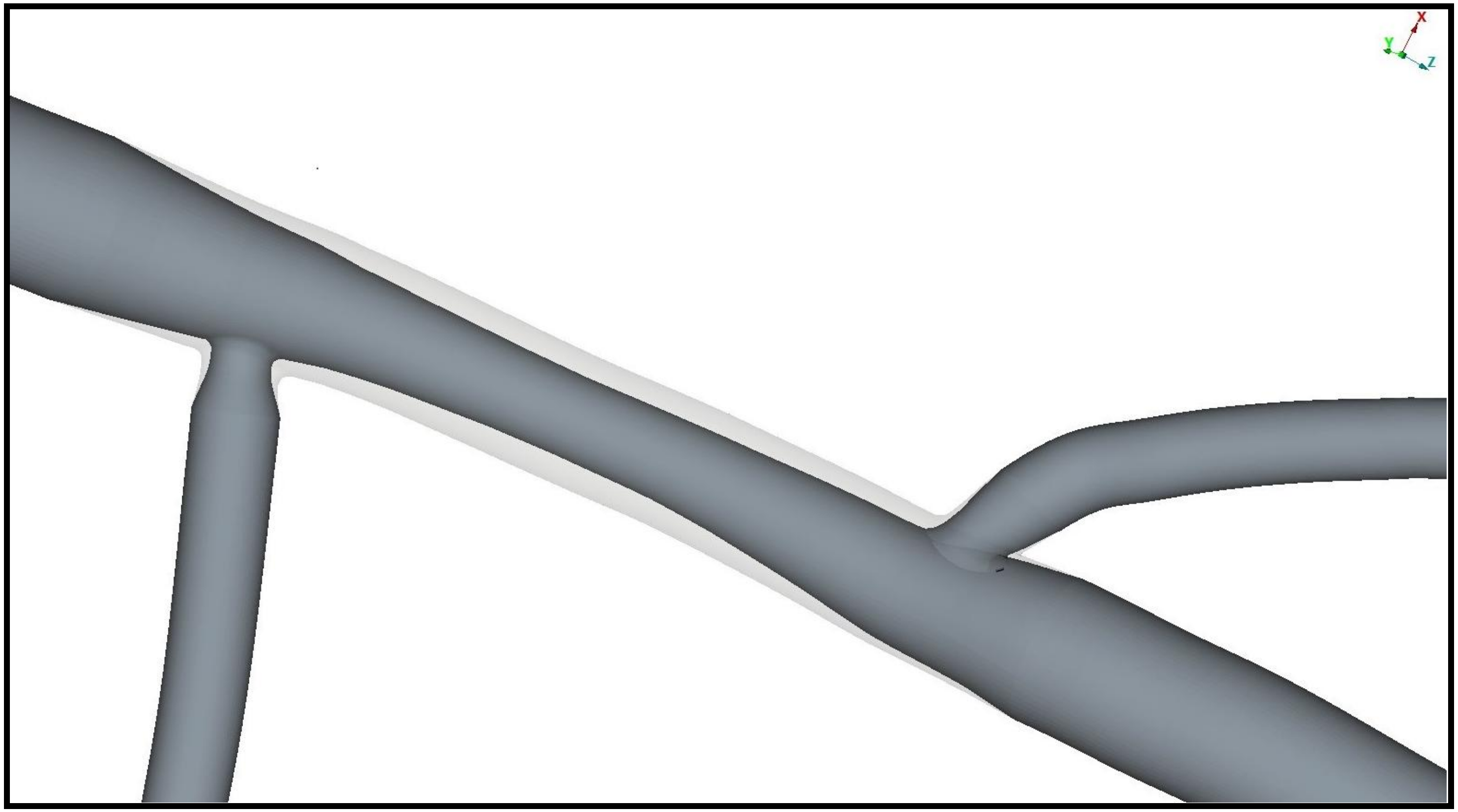
Python script in ANSA

Linear interpolation of grid points (user defined factor)

Model with user defined degree of stenosis (0-90%)

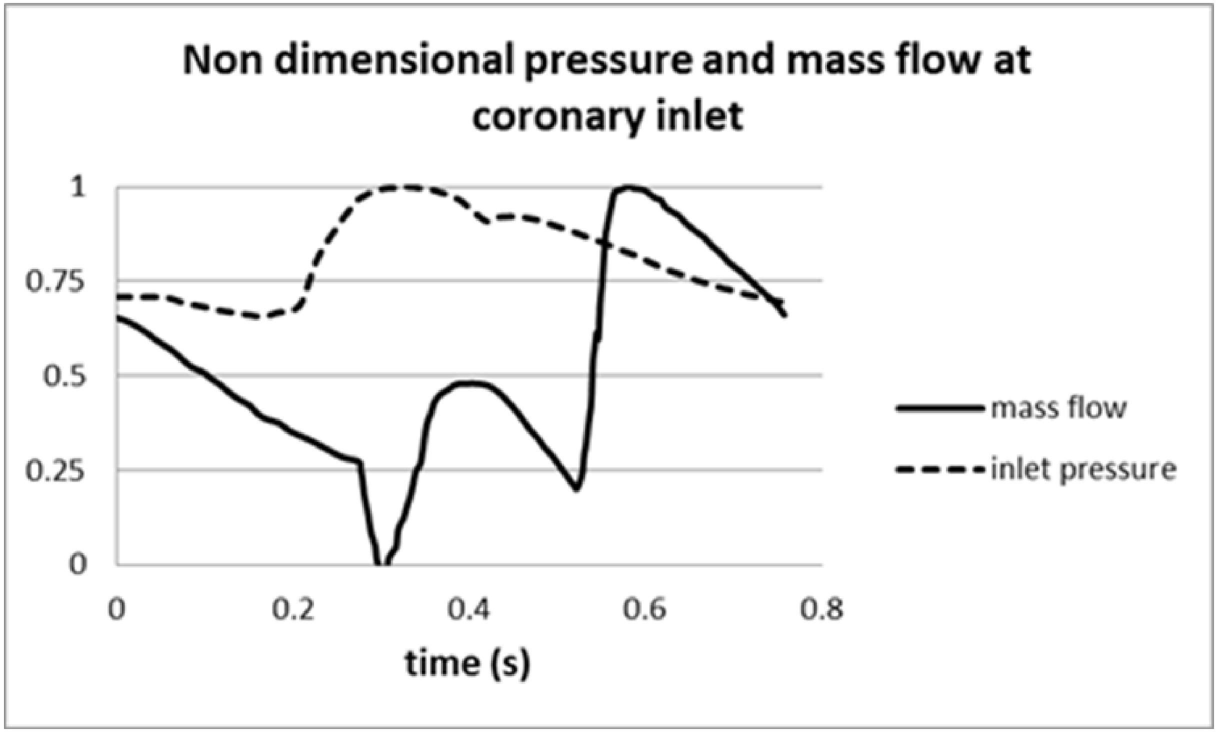
Mesh modification

Geometries with stenosis between 0 and 90



The problem of boundary conditions for CA

Coronary flow is determined by the downstream network



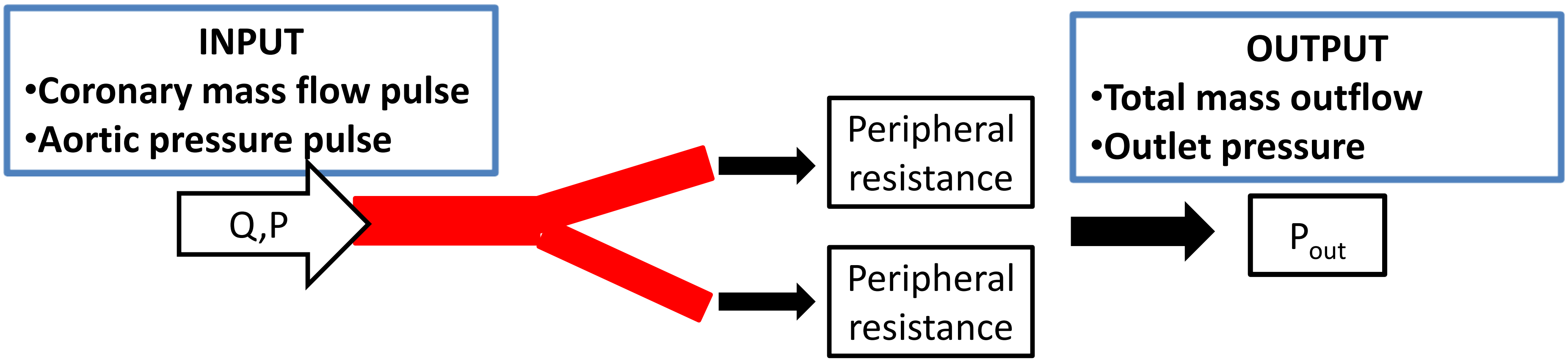
2. Flow distribution in healthy vessel

Assumption: constant wall shear stress
Flow rates are determined by the diameters

$$\tau_w = \frac{4\mu Q}{\pi r^3} \Longrightarrow \cdots \Longrightarrow \frac{Q_1}{r_1^3} = \frac{Q_2}{r_2^3}$$

Flow simulation: Calculation of pressure on every outlet of the geometry

Flow distribution in stenosed vessel



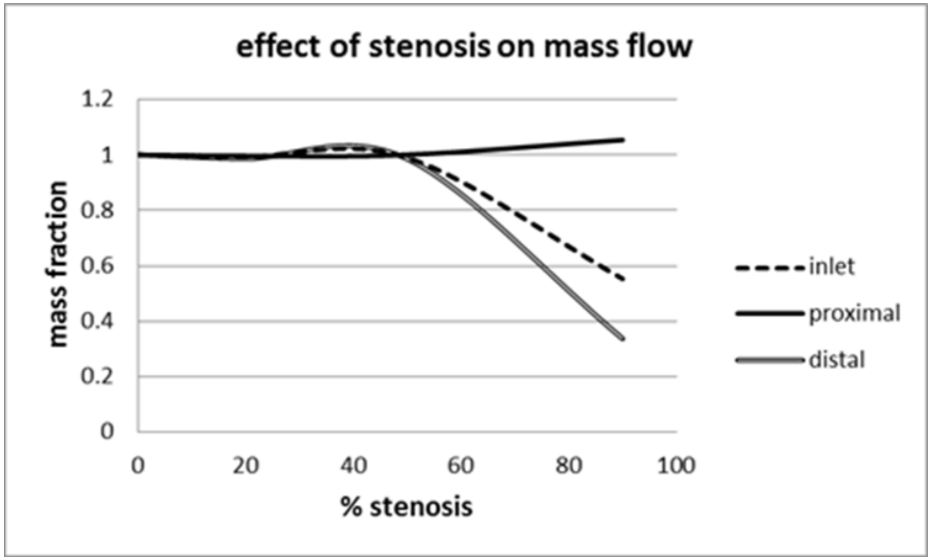
- Use a determined pressure drop for the whole system
- Calculate peripheral resistance from healthy vessel
- Correct mass flow outlets for stenosed vessel

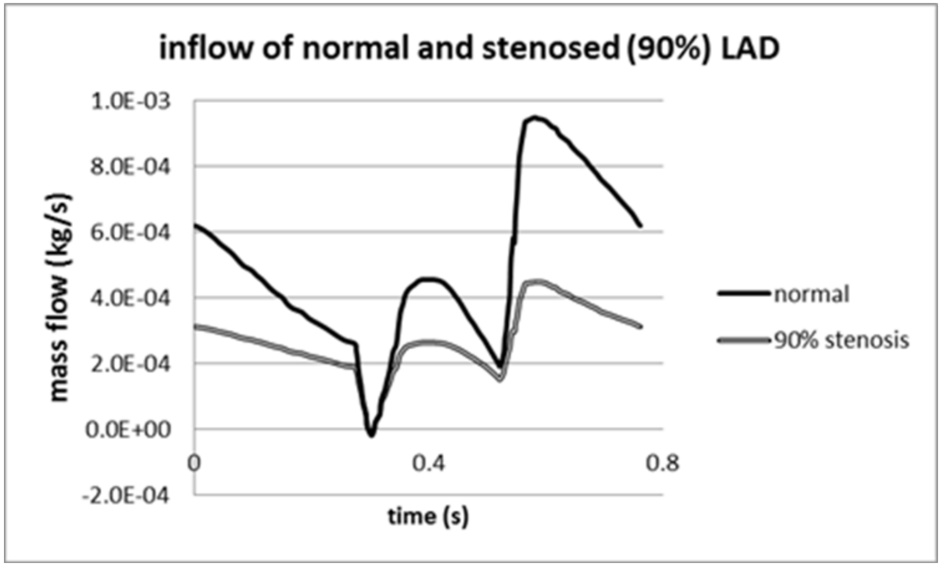
Simulation setup

- Rigid and stationary walls, no slip condition.
- Laminar flow (Reynolds numbers <100)
- Blood modelled as Newtonian fluid of viscosity of $\mu = 3.5 \cdot 10^{-3} Pa$ and density $\rho = 1.06 \cdot 10^{3} kg/m^{3}$.
- Incompressible Navier-Stokes equations were used:

$$\rho \frac{\partial u}{\partial t} = -\nabla p + \mu \nabla^2 u + F,$$
$$\nabla u = 0$$

Flow rates for stenosed vessels





- Significant change only for the case of severe stenosis
- Differentiation of stenosis effect for proximal and distal side branches

Results representation

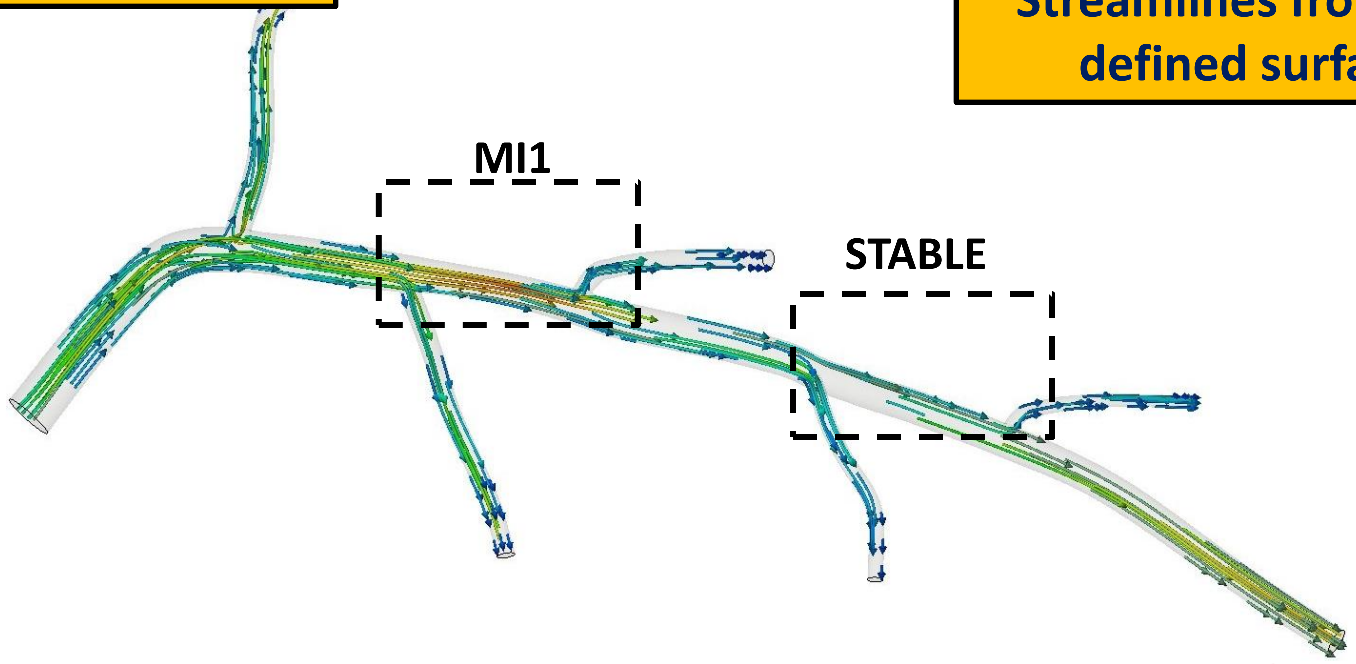
- The geometry and flow is not XYZ oriented
- Transient simulations

Centreline points

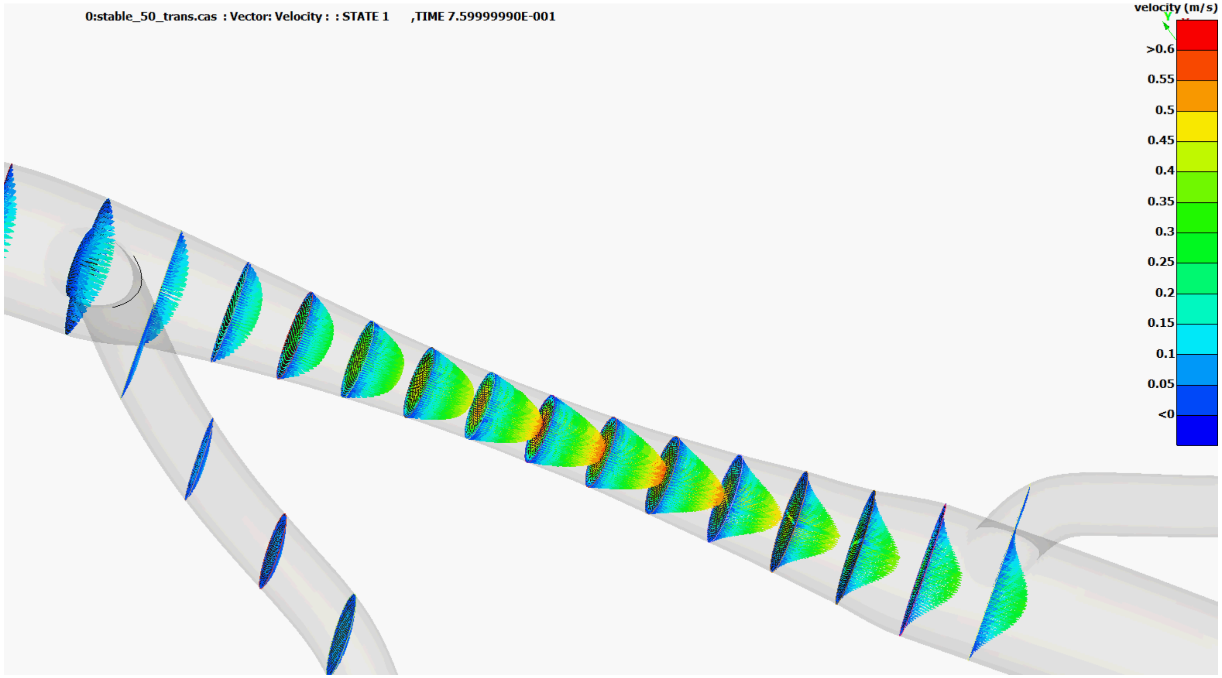
Beta script in μETA

Velocity profiles on user defined planes

Streamlines from user defined surfaces



Velocity profiles STABLE 50% stenosis

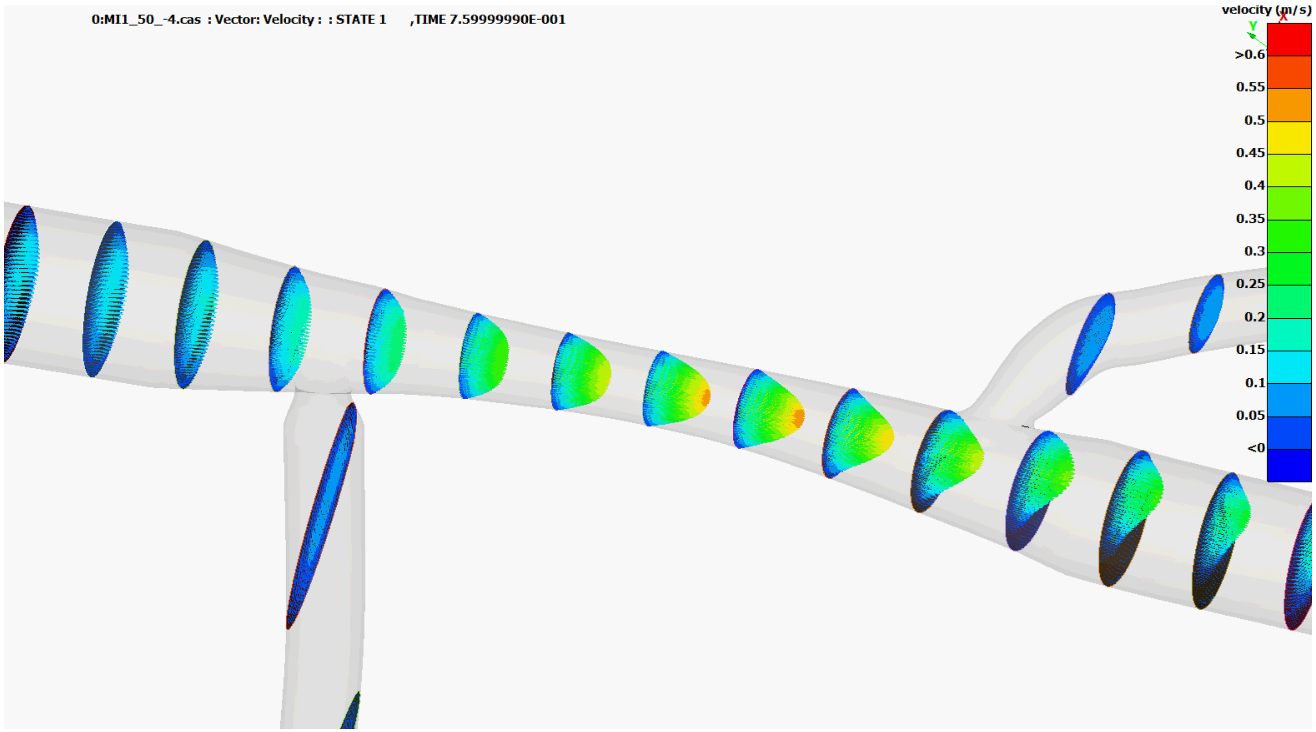


Custom plane cuts using the centreline points :

Increased shear in stenotic lesion

Disturbed velocity profile distal the stenosis

Velocity profiles MI1 50% stenosis



Custom plane cuts using the centreline points :

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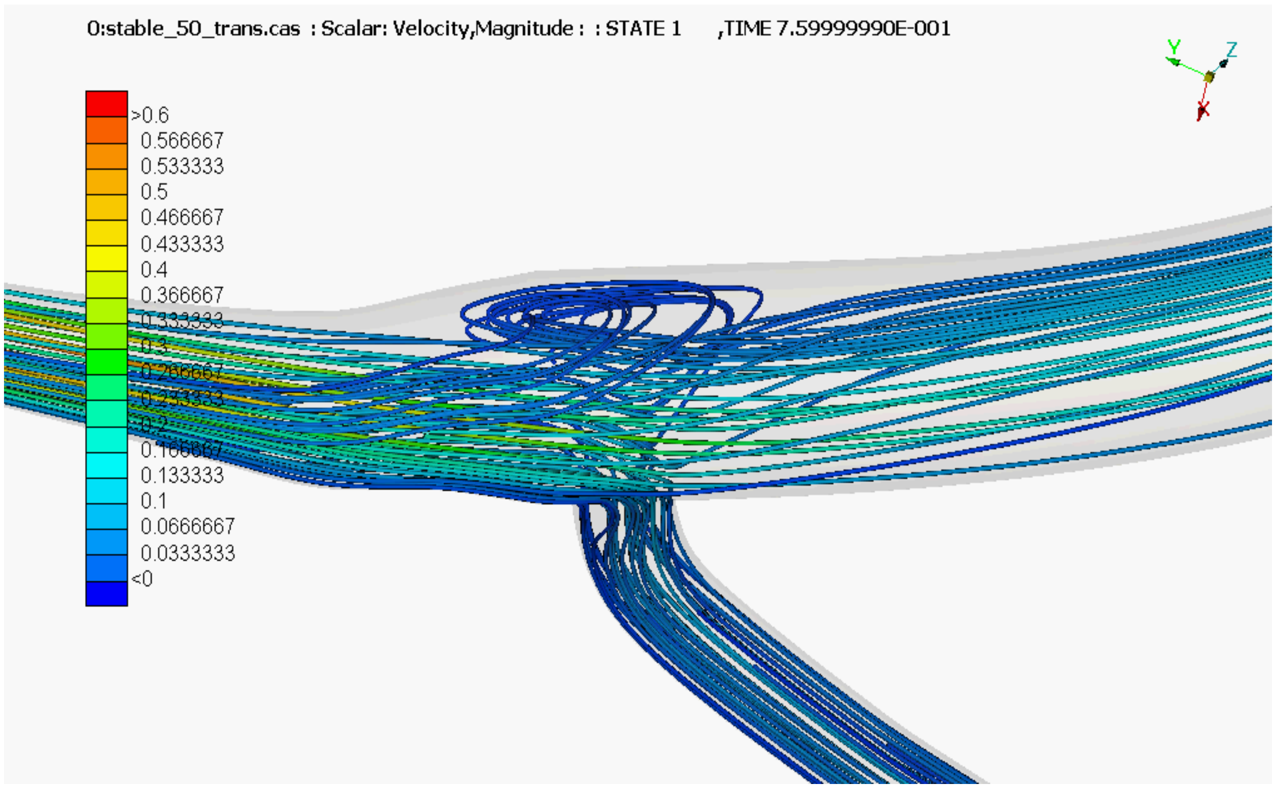
Streamlines STABLE 50% stenosis

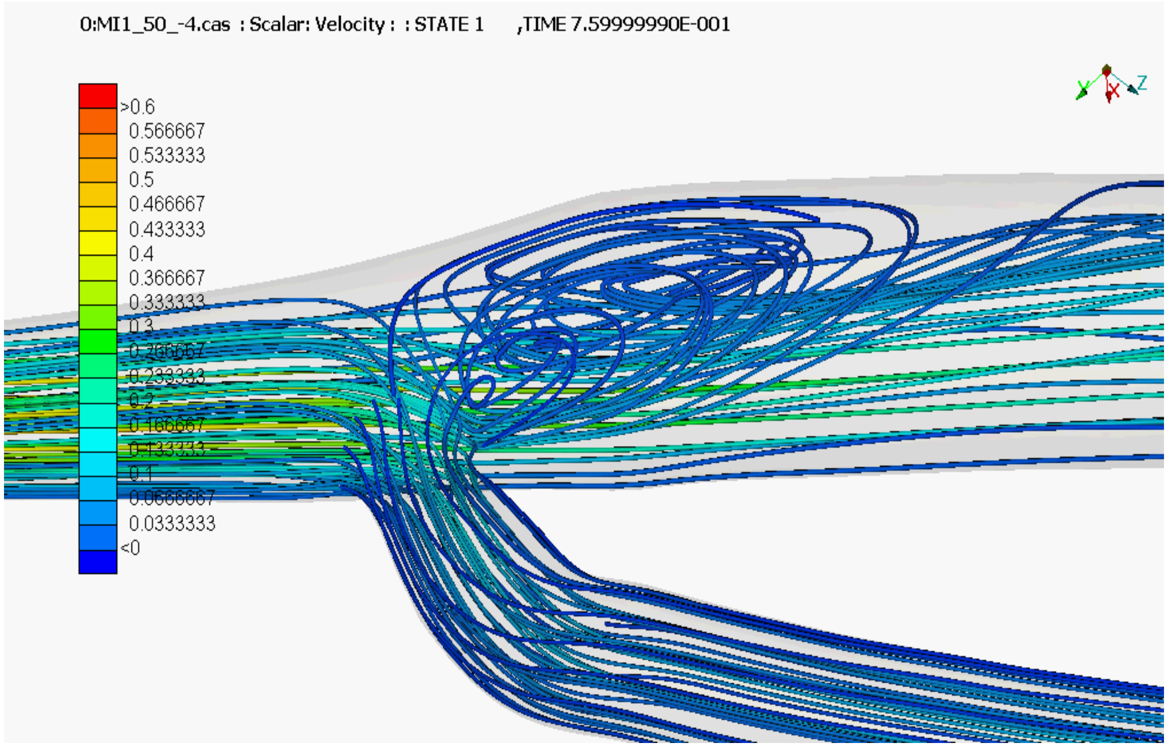


Velocity coloured streamlines downstream the stenosis:

Recirculation area (small part of heart cycle)

Small part of vortex streamlines lead into the side branch

Streamlines MI1 50% stenosis



Velocity coloured streamlines at the end of stenotic lesion

Recirculation area (considerable part of heart cycle)

Significantly more vortex streamlines lead into the side branch

conclusions

- **This study successfully demonstrated the ability of CFD to capture the effect of different location of stenosis on flow**
- **In the MI1 case the recirculation zone is larger both spatially and in time than in the STABLE case**
- **In the MI1 case part of recirculating flow appears to enter the side branch**
- **Modification of geometry using was made possible ANSA and Python scripting and reduced pre-processing time significantly.**
- **Consistent post processing and reporting of results using μETA and BETA scripting.**

Special thanks to BETA support team

Thank you

3. … a little more on the BETA script

Create hexa-block boxes with ogrid for NORMAL geometry (mesh 0)

Fitting created hexa-boxes on models with maximum stenosis (*not* ogrid)

Create ogrid for models with maximum stenosis

Export curves from mesh *and* ogrid of stenosed model

Fit original NORMAL mesh and ogrid on the exported curves (mesh 1)

From mesh 0 and mesh 1 using a script that interpolates the point coordinates we can obtain any intermediate geometry