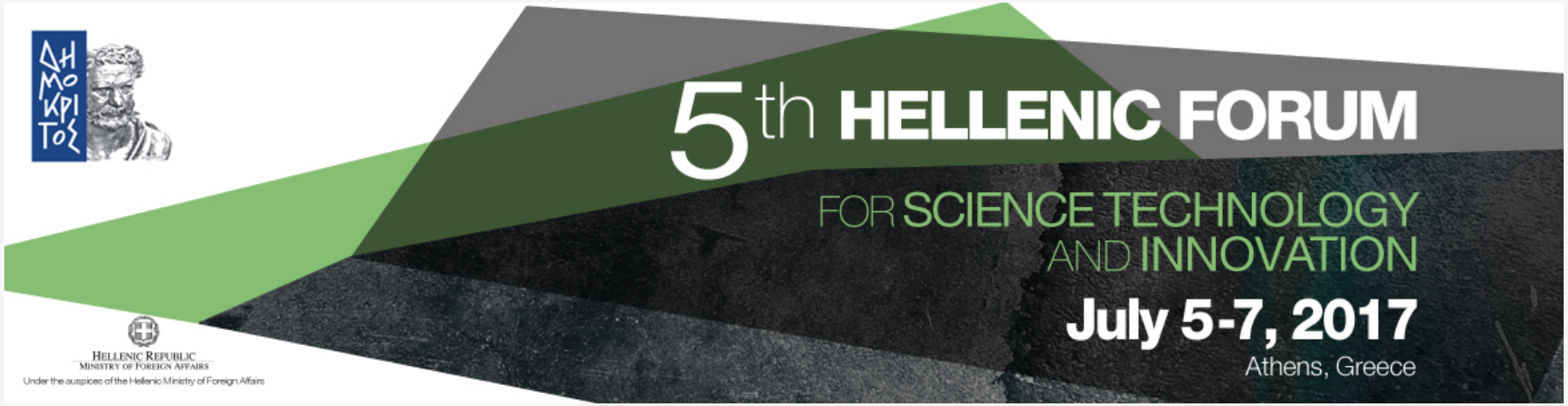

Towards *in silico* trials of therapeutic nanoparticles

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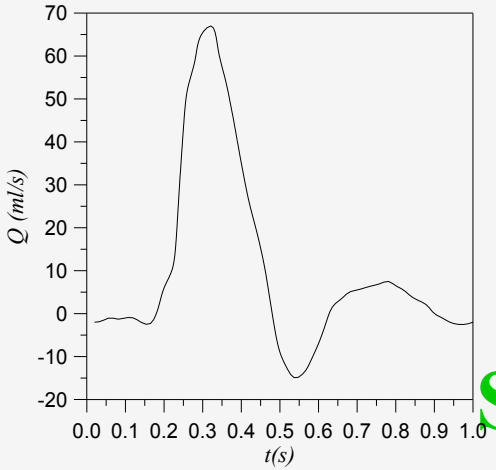
National Center for Scientific Research 'Demokritos'

Overview

1. Introduction to Computational Fluid Dynamics
2. Medical Imaging Data Processing
   i. Grid Generation
3. Application 1: Abdominal Aortic Aneurysm
   i. Flow-particle field
   ii. Gravity effects on particle deposition
4. Application 2: Iliac Bifurcation
   i. Flow-particle field
   ii. Deposition aspects
5. Ongoing research

Introduction to Computational Fluid Dynamics

Boundary Conditions



Discretization

Geometry

Solution

CFD Software

Flow field

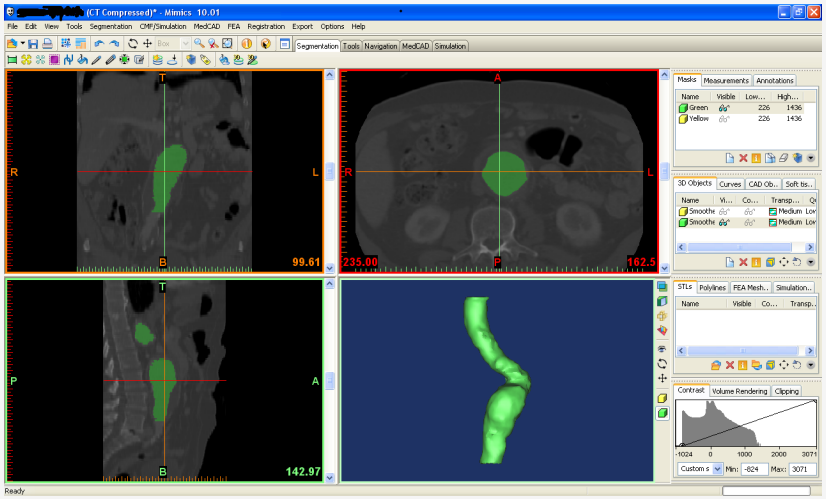
Equations

Differential Equations for Fluid Mechanics

- Continuity
- Momentum

Differential Equations for Particle Dynamics

Medical imaging data processing



Medical imaging data visualization

- Clinical data from medical imaging devices (MRI, CT etc)

Geometry segmentation

- User intervention
- Luminescence thresholds

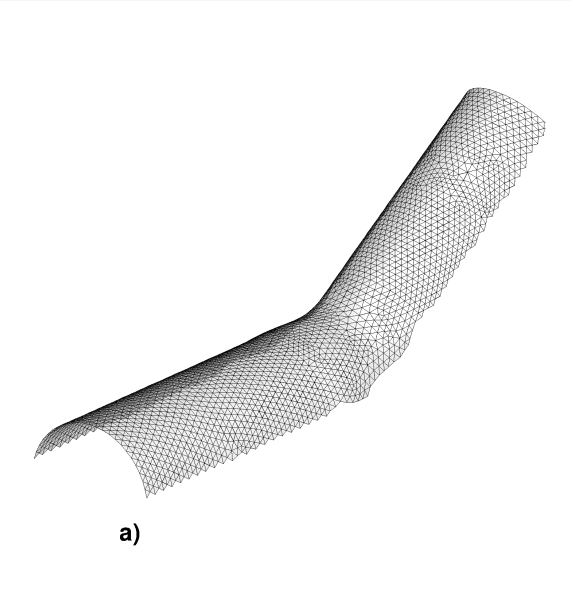
Geometry reconstruction

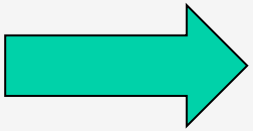
- Medical imaging commercial software
- Results in a low quality triangulated surface (STL file) representing the Volume of interest (VOI)

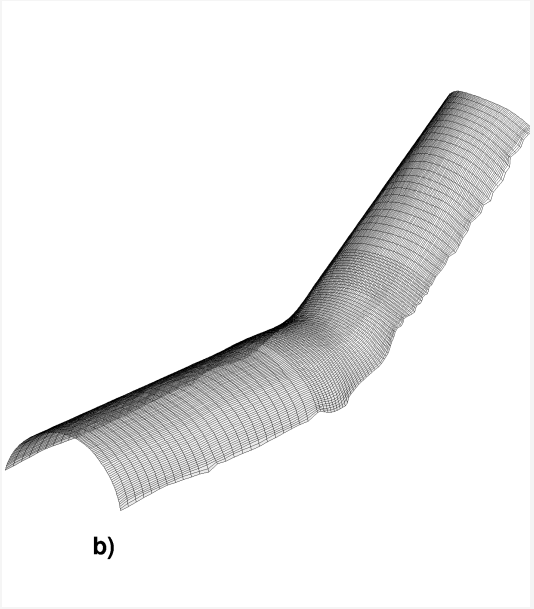
Grid Generation

STL file or surface triangulation in 3D

surface in 3D with structured grid

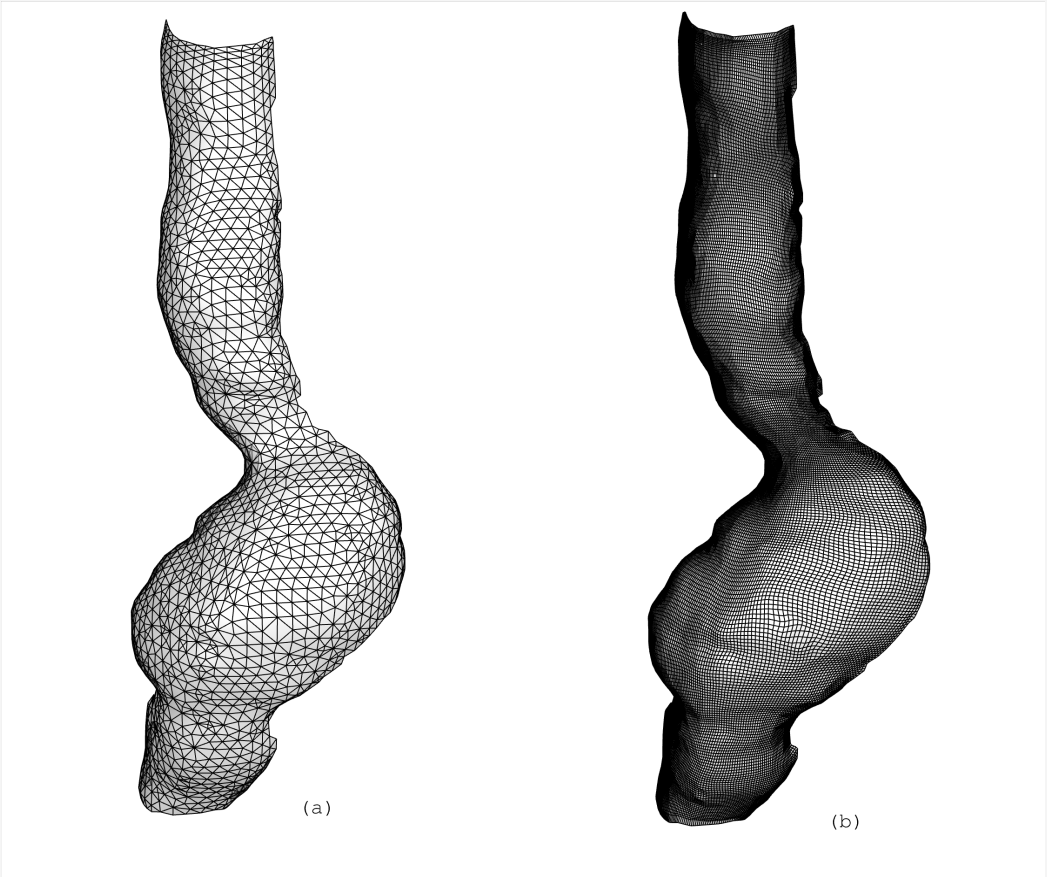






- By the use of the invariant barycentric coordinates calculated on the planar grid the structured surface grid is created.
- Unification of the surface grids according to a selected topology.
- Initial volume grid creation → Grid enhancement methods (Sorenson, Thomas Middelhoff e.t.c.)

Application 1
Abdominal Aortic Aneurysm (AAA)

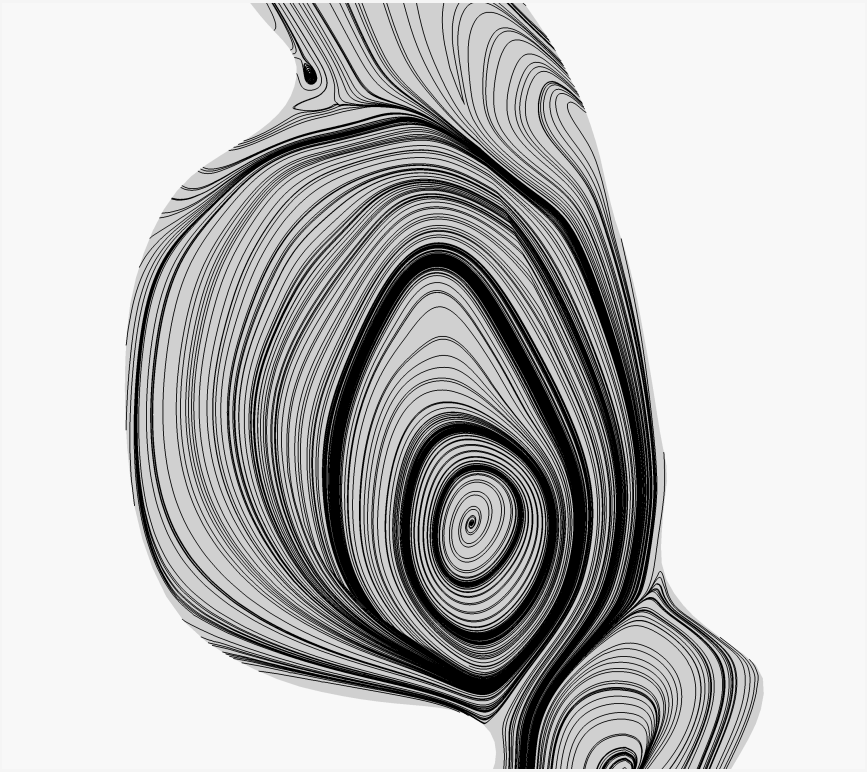


- An abdominal aortic aneurysm (AAA) is a common abnormality of the human cardiovascular system.
- Particle diffusion assessment by patient specific engineering simulations.
- Multi-block structured AAA computational domain with element clustering near the wall.

Application 1
Abdominal Aortic Aneurysm (AAA)

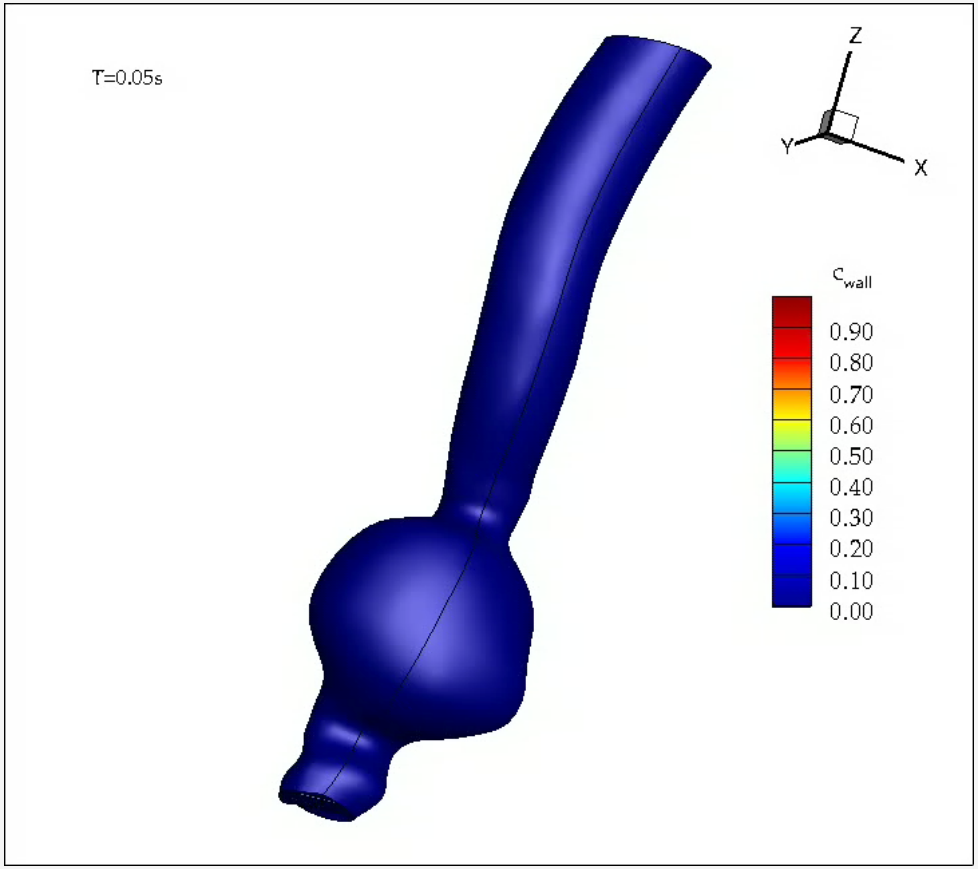
Wall displacement

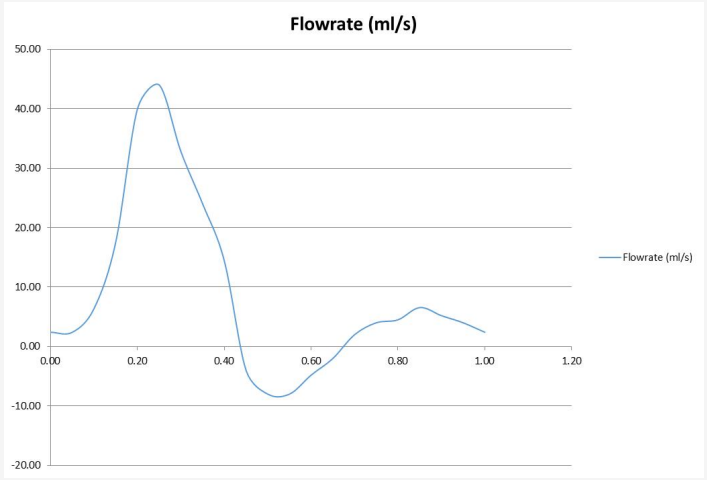
Flow field



Application 1
Abdominal Aortic Aneurysm (AAA)

Nanoparticle wall-concentration with gravity

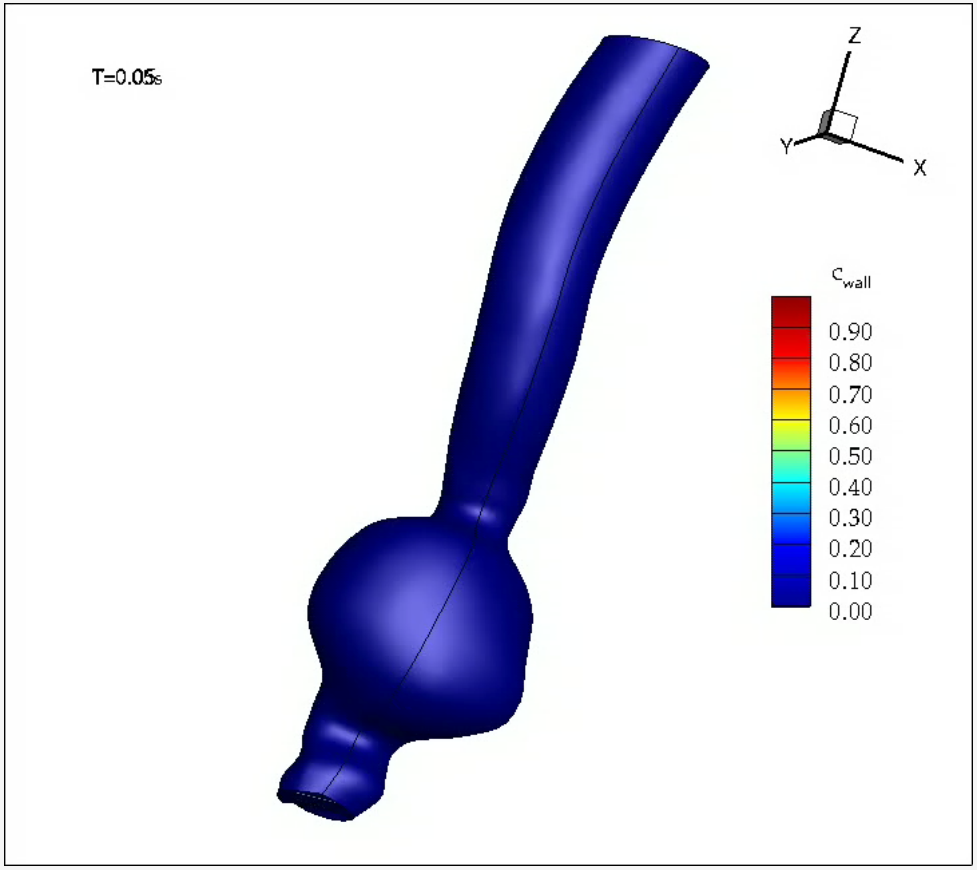


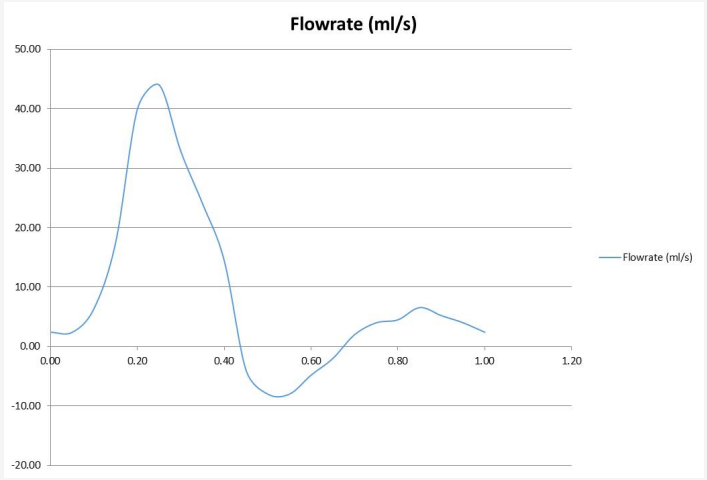


Parameter	Value
Blood's temperature	$T = 310K$
Blood's density	$\rho_f = 10^3 kg \cdot m^{-3}$
Blood's viscosity	$\mu_f = 4 \cdot 10^{-3} kg \cdot m^{-1} \cdot s^{-1}$
Particles' density	$\rho_p = 6450 kg \cdot m^{-3}$
Particles' number concentration at the inlet	$N_{\text{inlet}}(\boldsymbol{x}, 0) = 10^{12} \text{particles} \cdot m^{-3}$
Particles' diameter	$d_p = 1 \mu m$
Strouhal number	$Str = 2.2 \cdot 10^{-4}$

Application 1
Abdominal Aortic Aneurysm (AAA)

Nanoparticle wall-concentration without gravity





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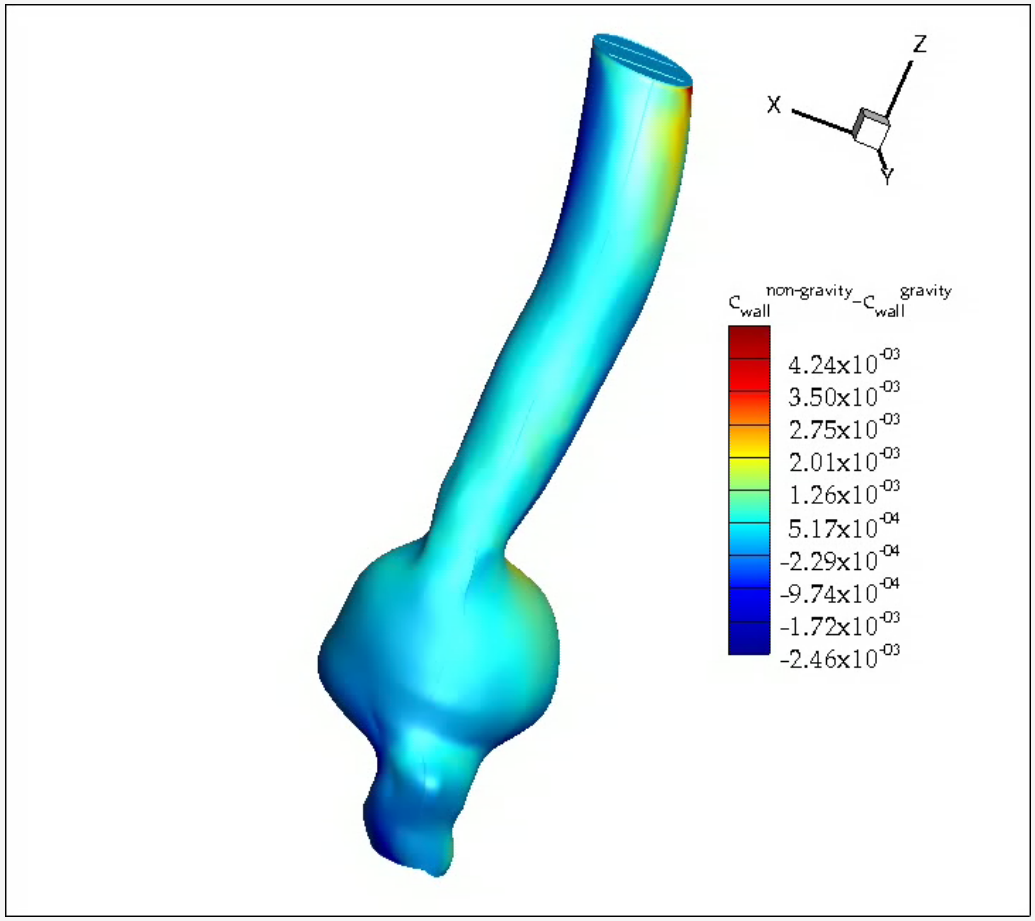
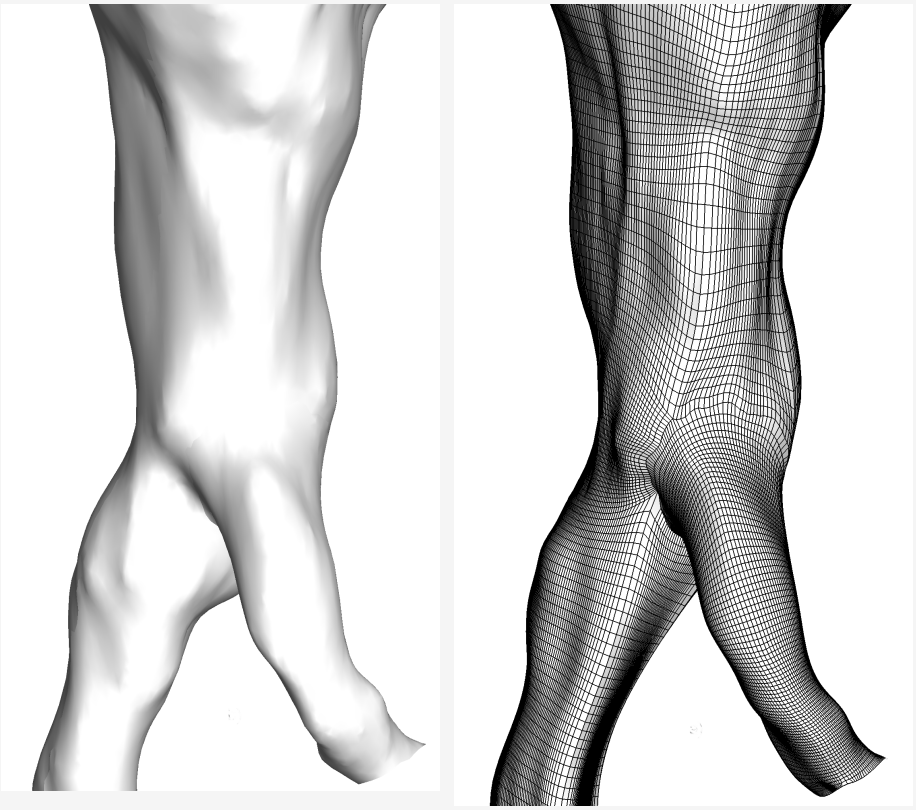
Application 1
Abdominal Aortic Aneurysm (AAA)

Comparison between cases

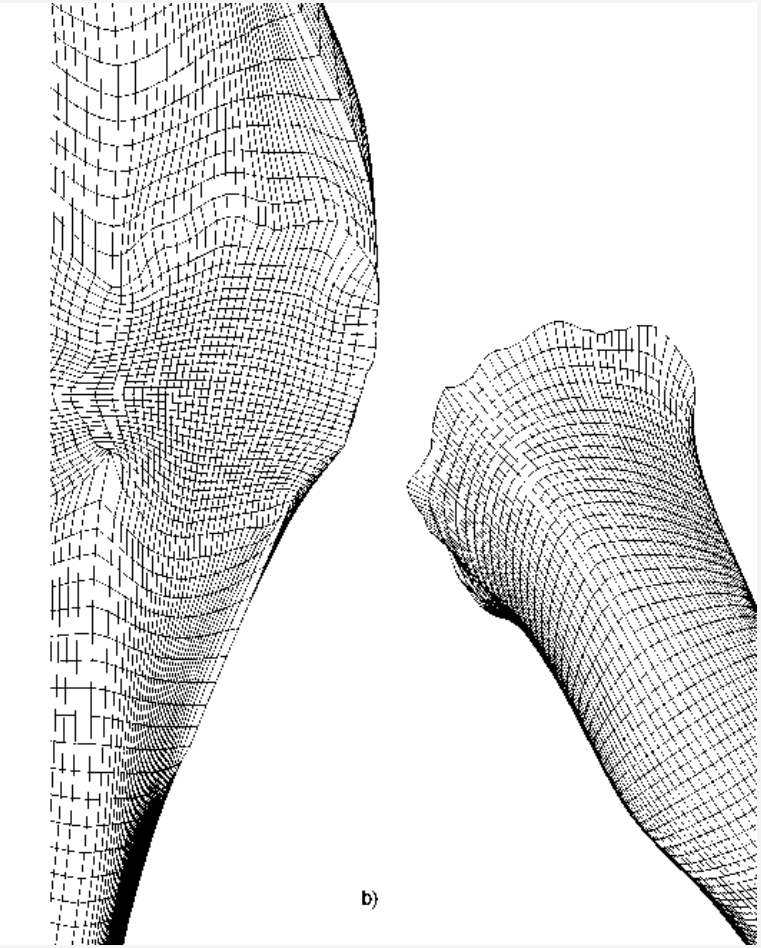


Application 2
Iliac Bifurcation



- Biomechanical applications include series of branching geometrical shapes.
- Great number of branching geometries inside the human body → Modeling of the branching geometry is an important task.
- Multi-block structured bifurcation computational domain with a one block per branch topology.

Application 2
Iliac Bifurcation



- Handy implemented technique for the grid preparation for one-to-one union of the two branches
- One block per branch topology

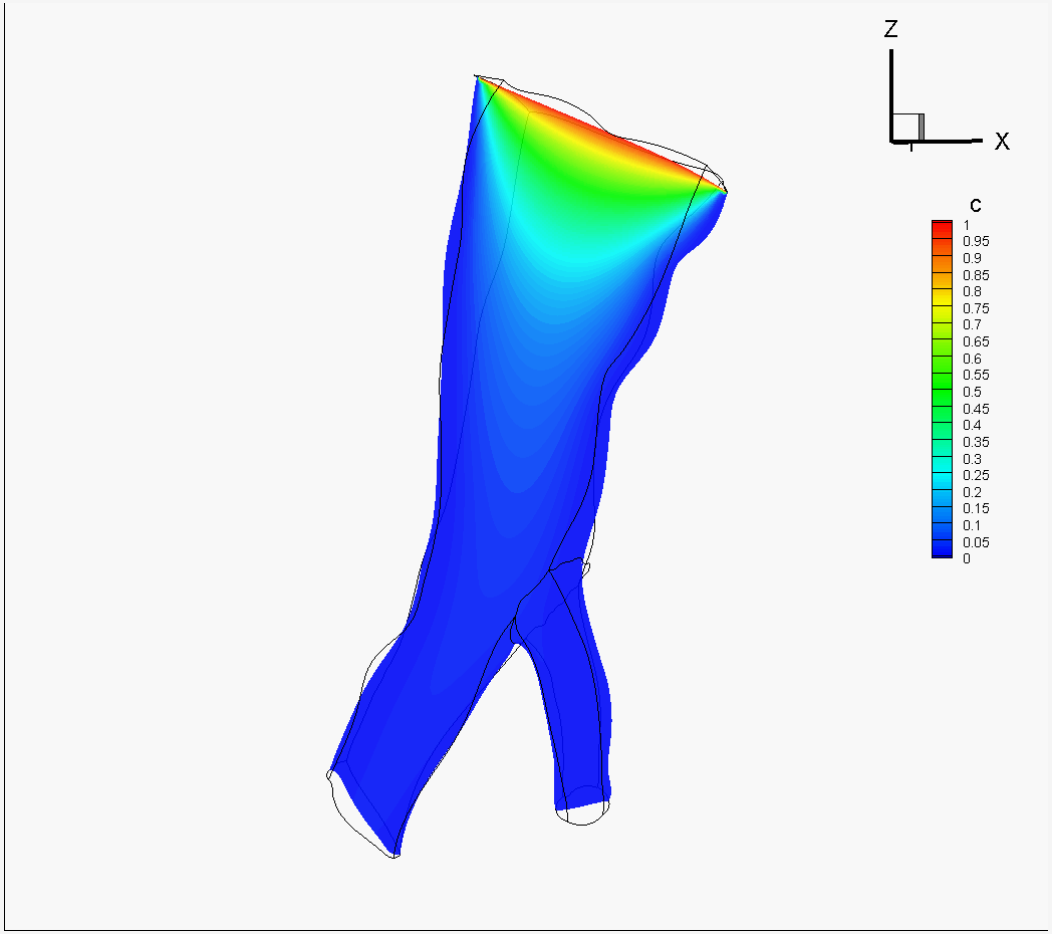
  + Topologically simple

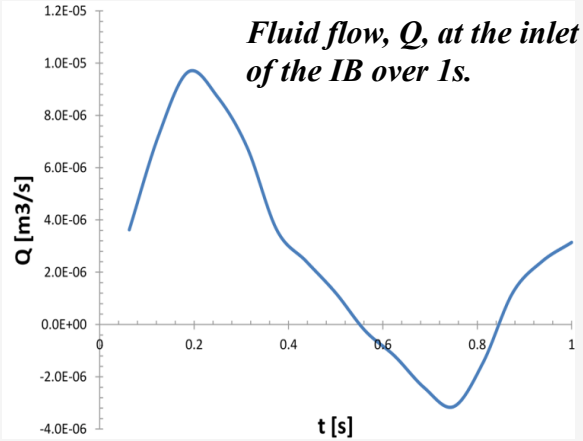
  + Able to adapt to multiple branching geometries (Aortic Arch, etc)

  - Presence of a few skewed elements at block corners

Application 2
Iliac Bifurcation

Particle concentration

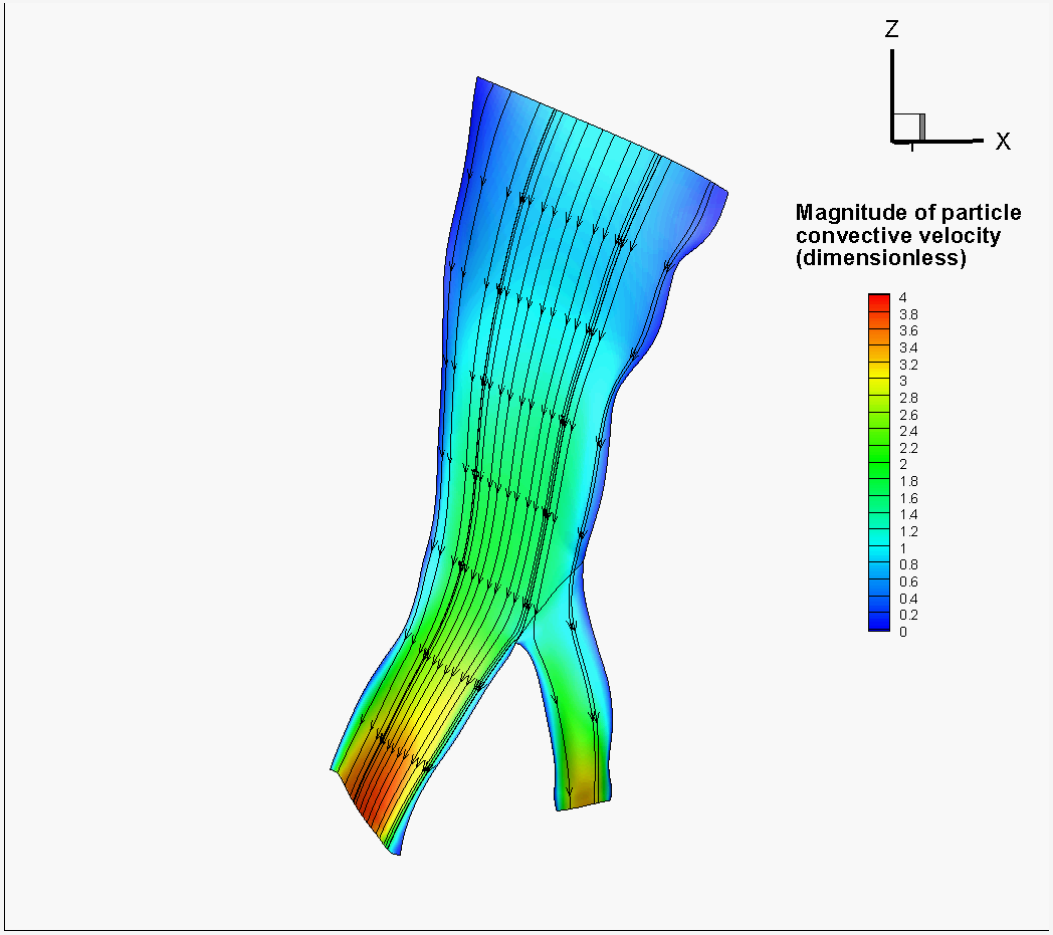




- Particle diameter d_p=1μm.
- Particles are released for 1s and their flow is calculated until they either exit or deposit.

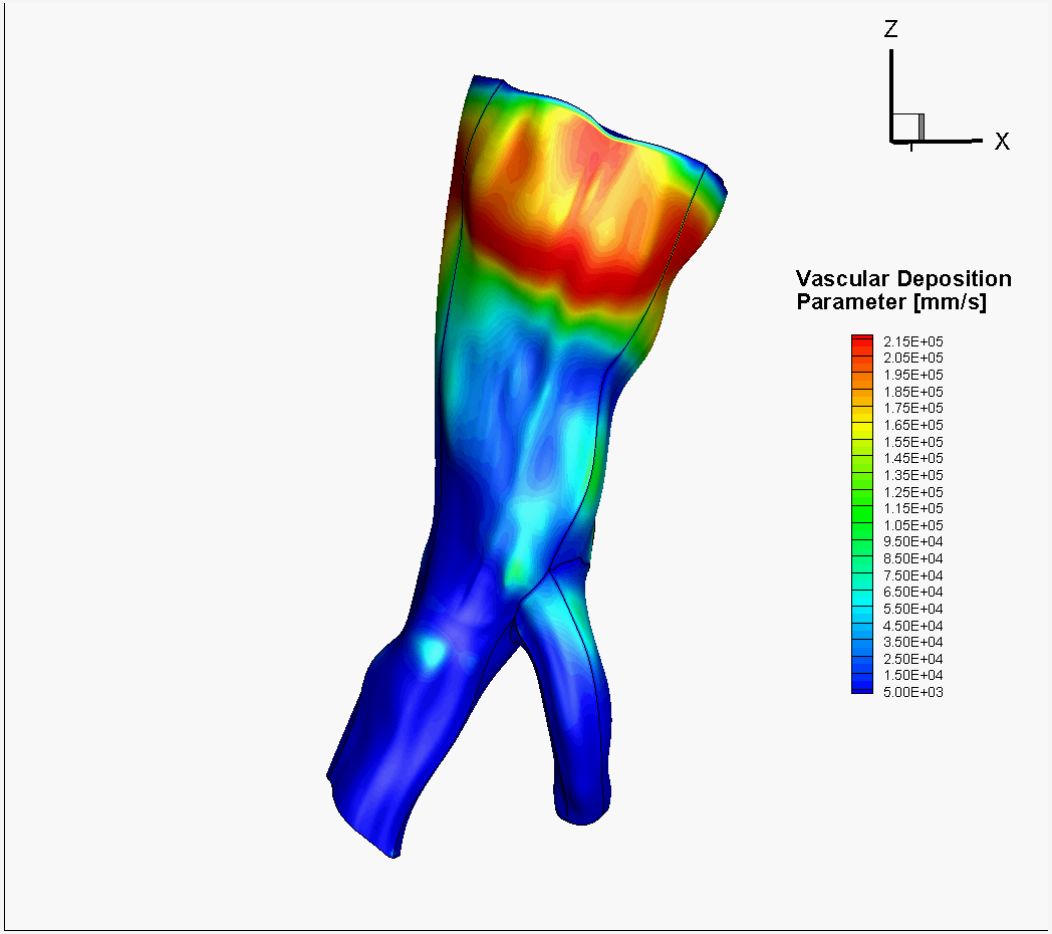
Application 2
Iliac Bifurcation

Particle convective velocity



Application 2
Iliac Bifurcation

Vascular Deposition Parameter

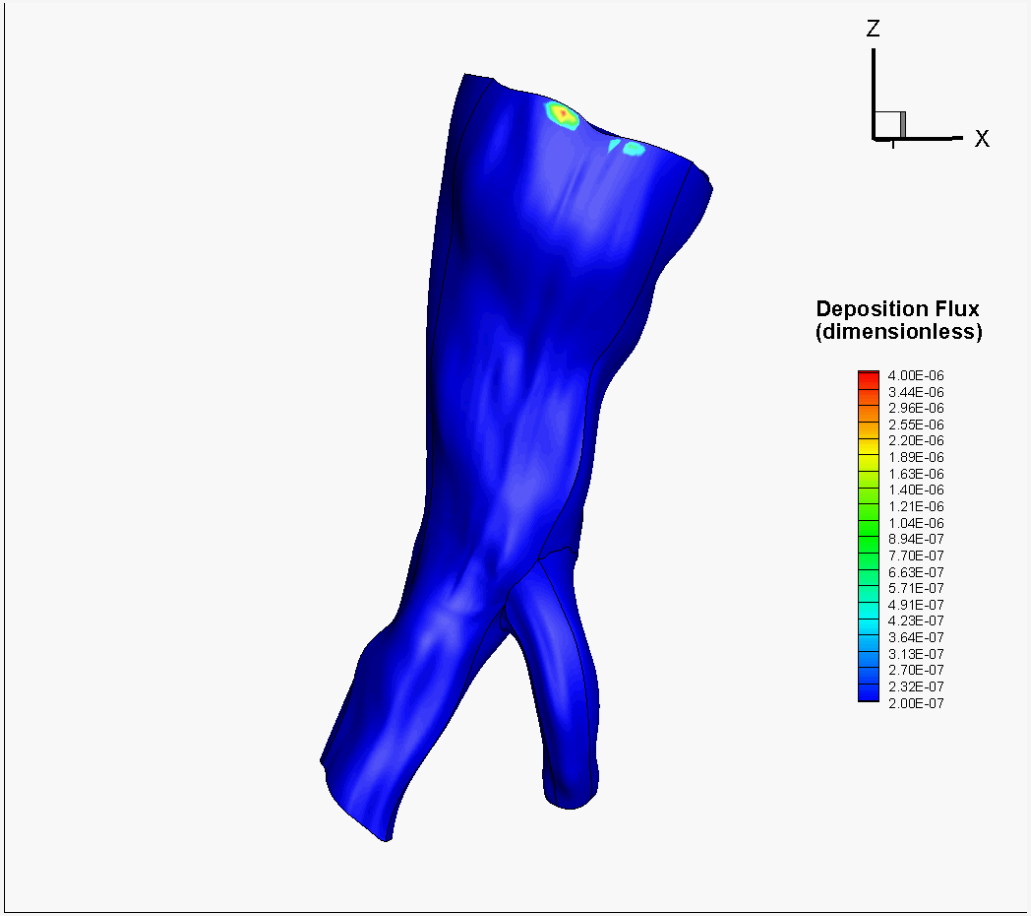


Vascular Deposition Parameter, Π [m/s]

$$\Pi = P_{a} \, S_{r_p}$$

Application 2
Iliac Bifurcation

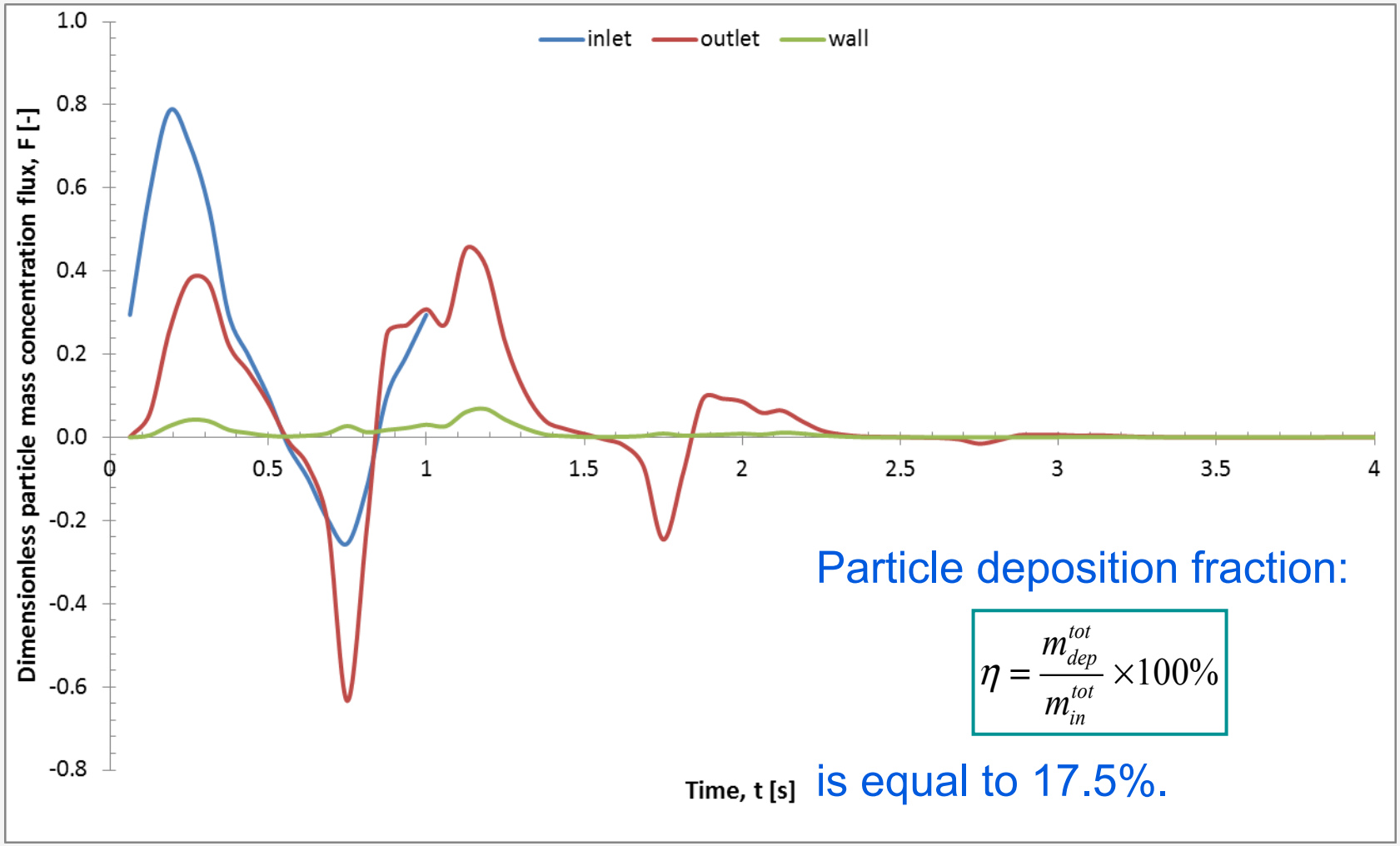
Deposition Flux



Adhesive Wall Boundary Condition

$$-D\partial c/\partial n\,|\downarrow wall = \Pi c|\downarrow wall$$

Application 2
Iliac Bifurcation

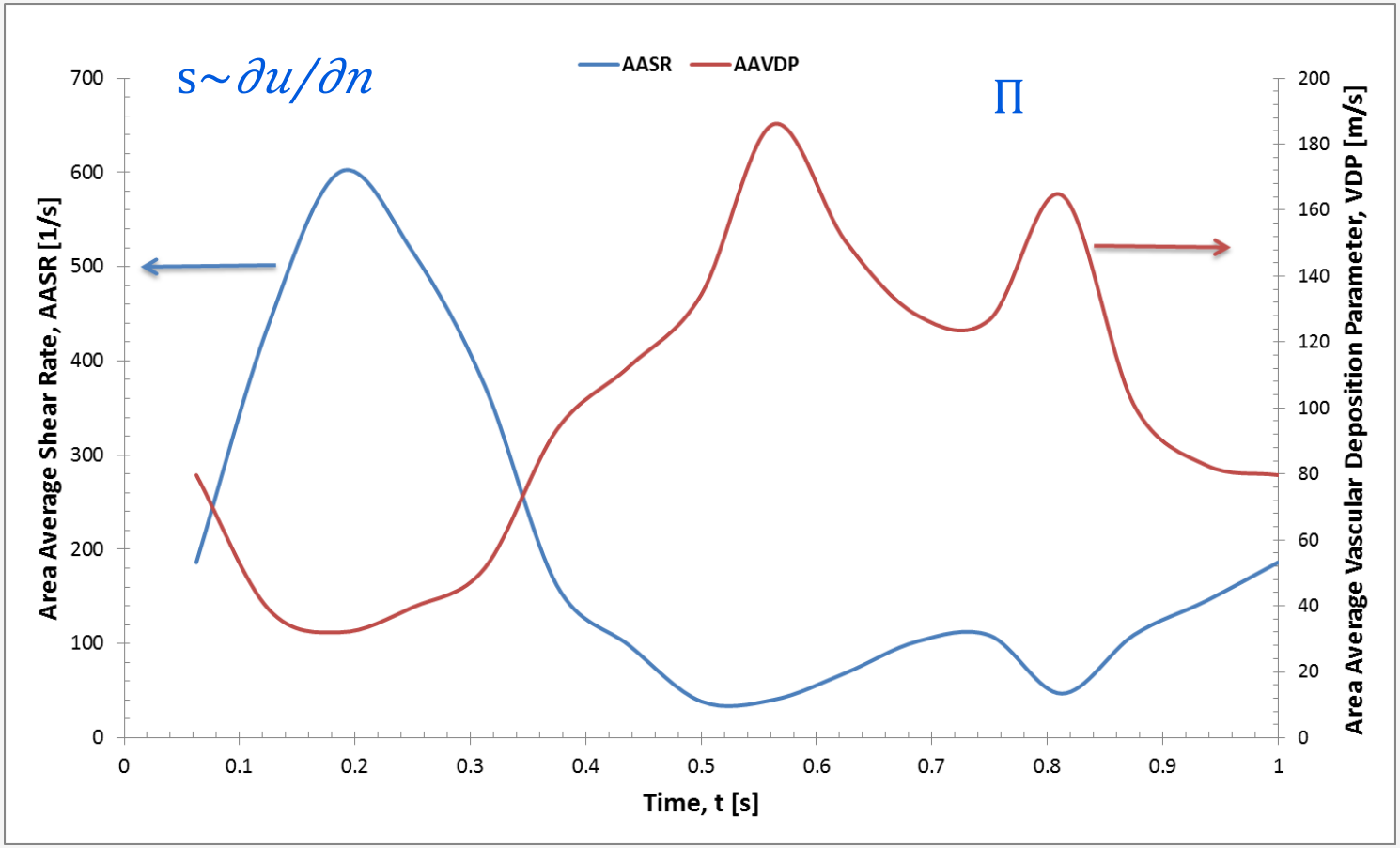


Particle deposition fraction:

$$\eta = \frac{m_{dep}^{tot}}{m_{in}^{tot}} \times 100\%$$

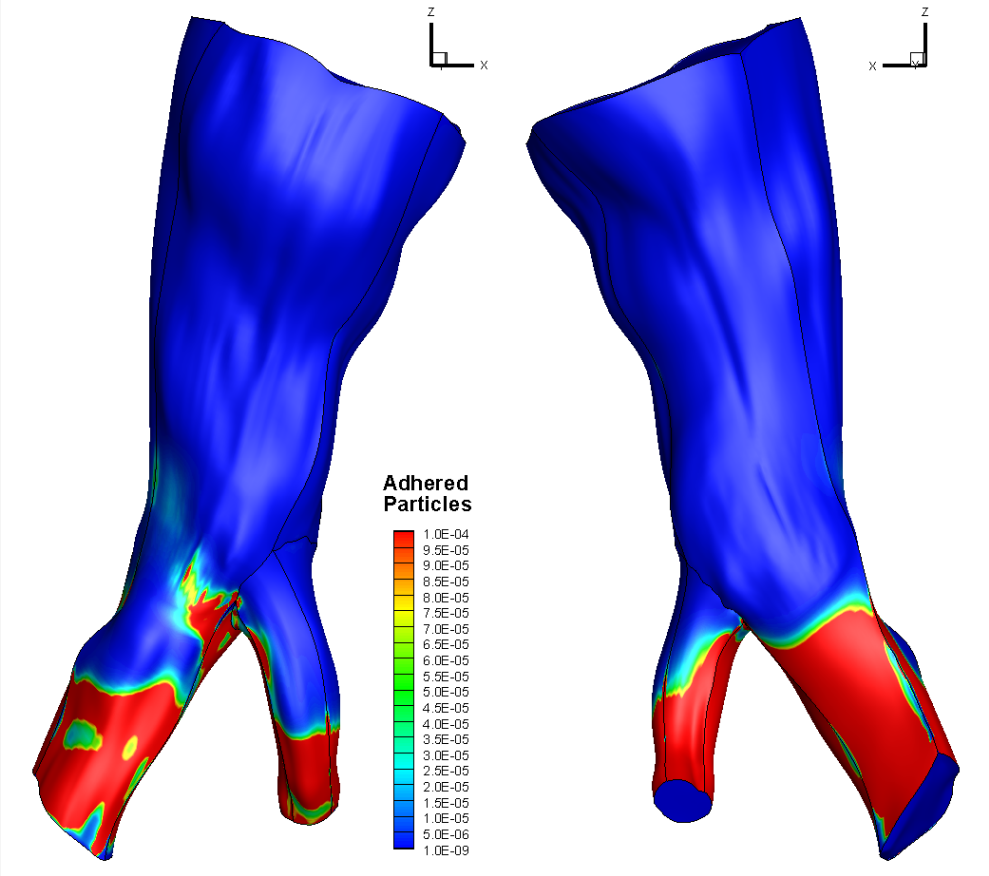
is equal to 17.5%.

Application 2
Iliac Bifurcation



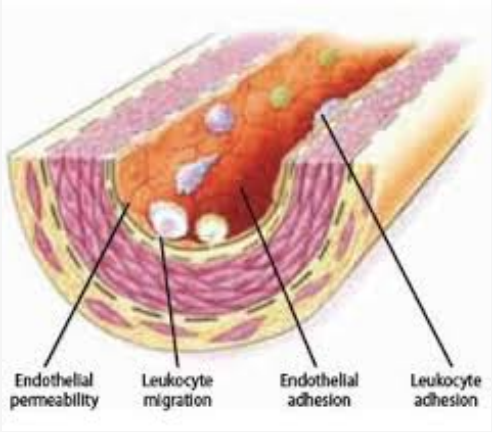
Application 2
Iliac Bifurcation

Particles adhered on the IB at the end of the simulations (when the IB is empty).

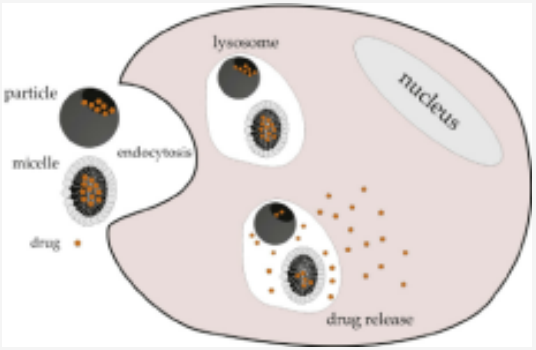


Ongoing Work

- *Vessel-wall infiltration and diffusion*



- *Cell-uptake of nanoparticle and drug release*



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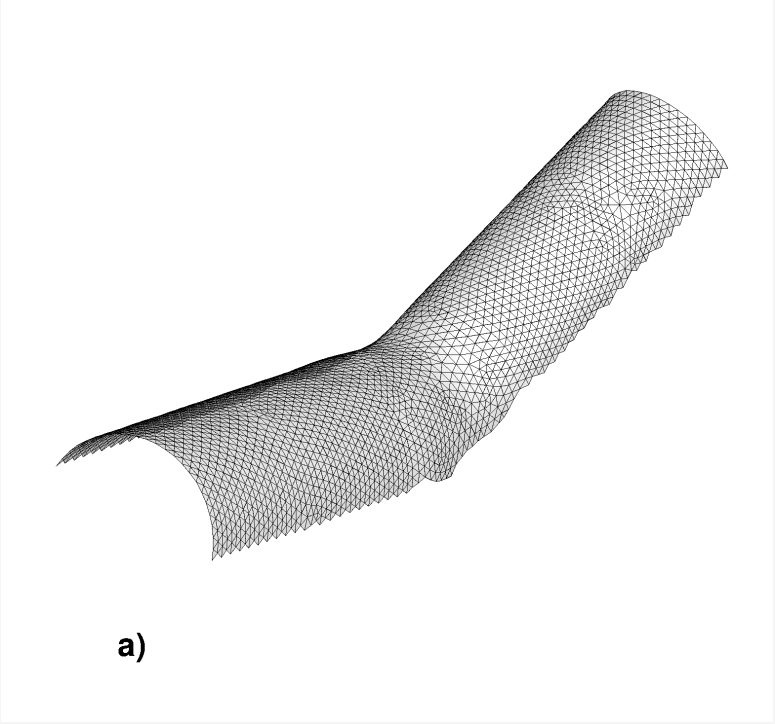
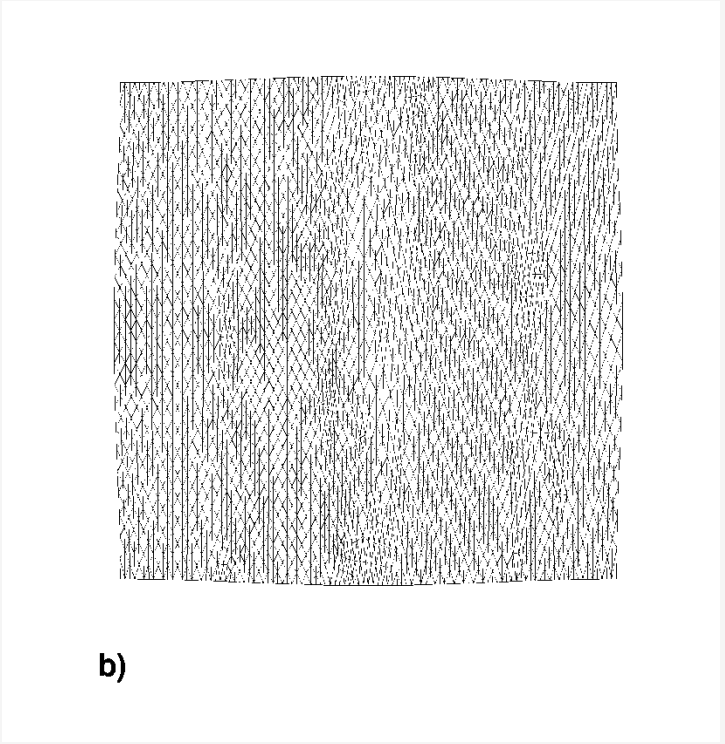
Grid Generation

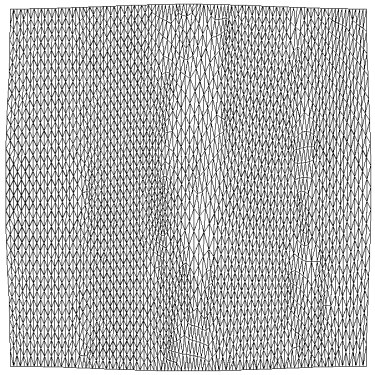




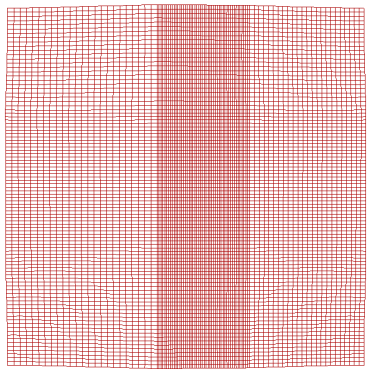
STL file or surface triangulation in 3D.

Planar triangulation in a predefined 2D domain.

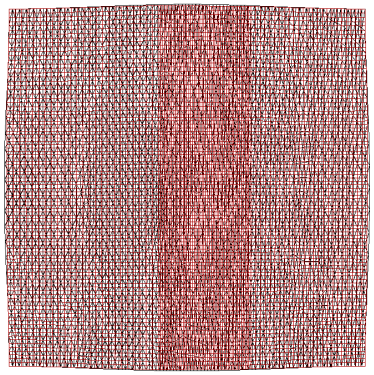
Grid Generation



a)



b)



c)

- Structured grid projection on the planar triangulation.
- Each structured grid vertex is located inside a triangle of the planar triangulation.
- The barycentric coordinates for each structured grid vertex are calculated.