Department of Hydrodynamic Systems

Benjamin Csippa
Department of Hydrodynamic Systems
Budapest University of Technology and Economics

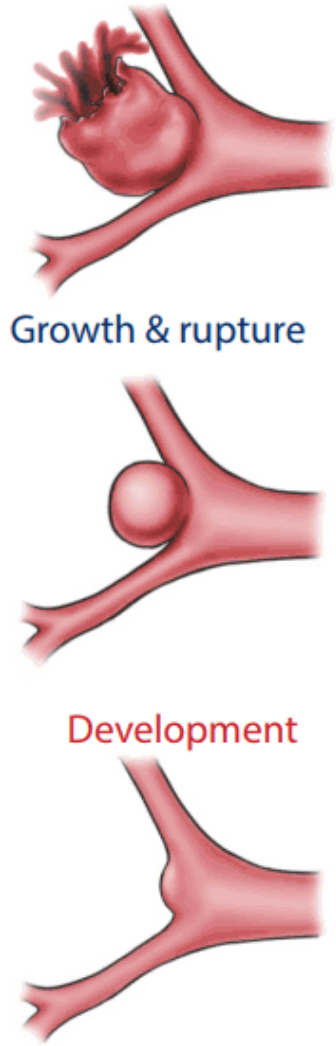
Medical imagind and numerical meshing

Outline

- CFD for blood flow?
- Applications?
- 1D simulations
  - Mathematical methods
- 3D simulations
  - Numerical meshing.
  - Simulation methodology

CFD in Hemodynamics

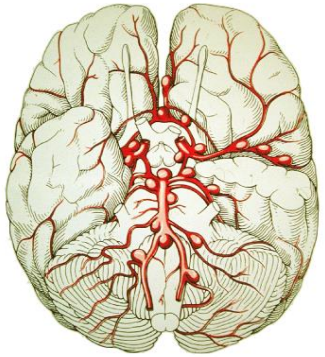
- Research
  - Phisics of disease
  - the disease pathogenesis (development)
- Treatment
  - Suggestion for devices
  - Follow up (longitudinal studies)

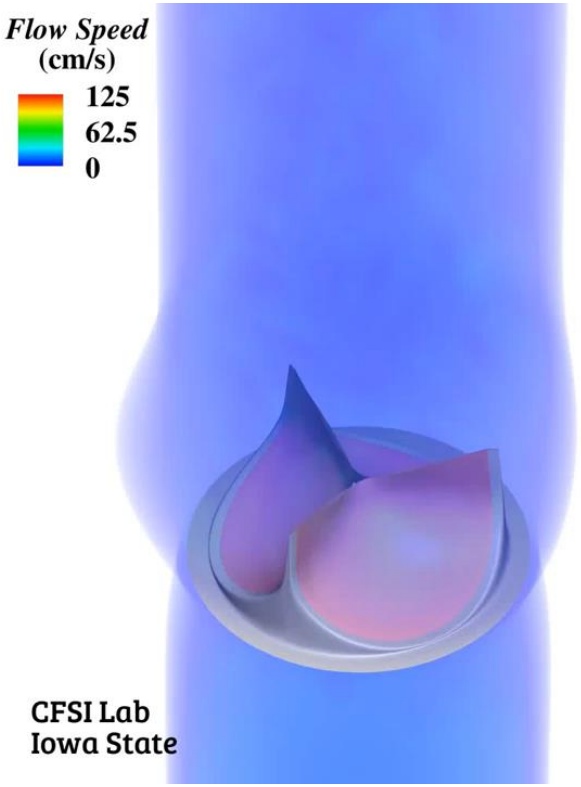


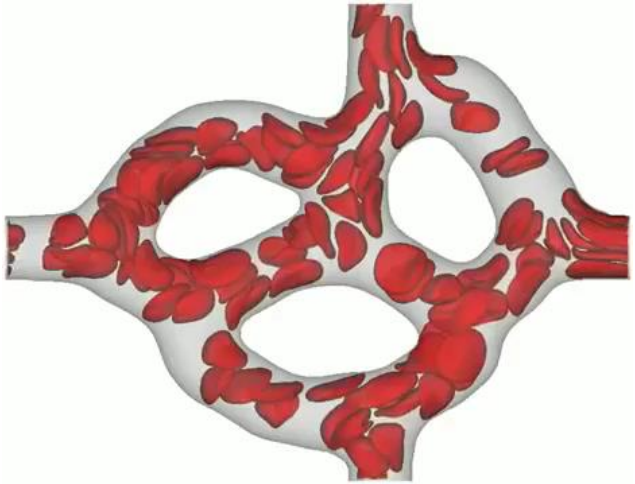
Keun-Hwa Jung et al. 2018 Neurointervention

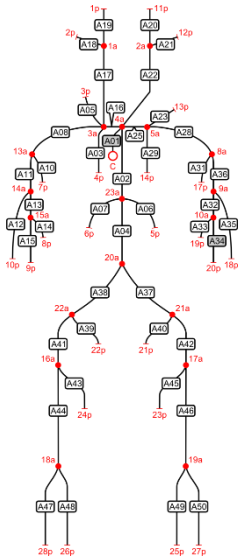
Applications

- In arteriovenous system (usually 1D)
- In coronary arteries (mostly 3D)
  - Stenosis
  - Stenting
- In the aorta (3D)
  - Abdominal aneurysms
  - Aortic valves
  - Stent-grafts
- Blood cell dynamics



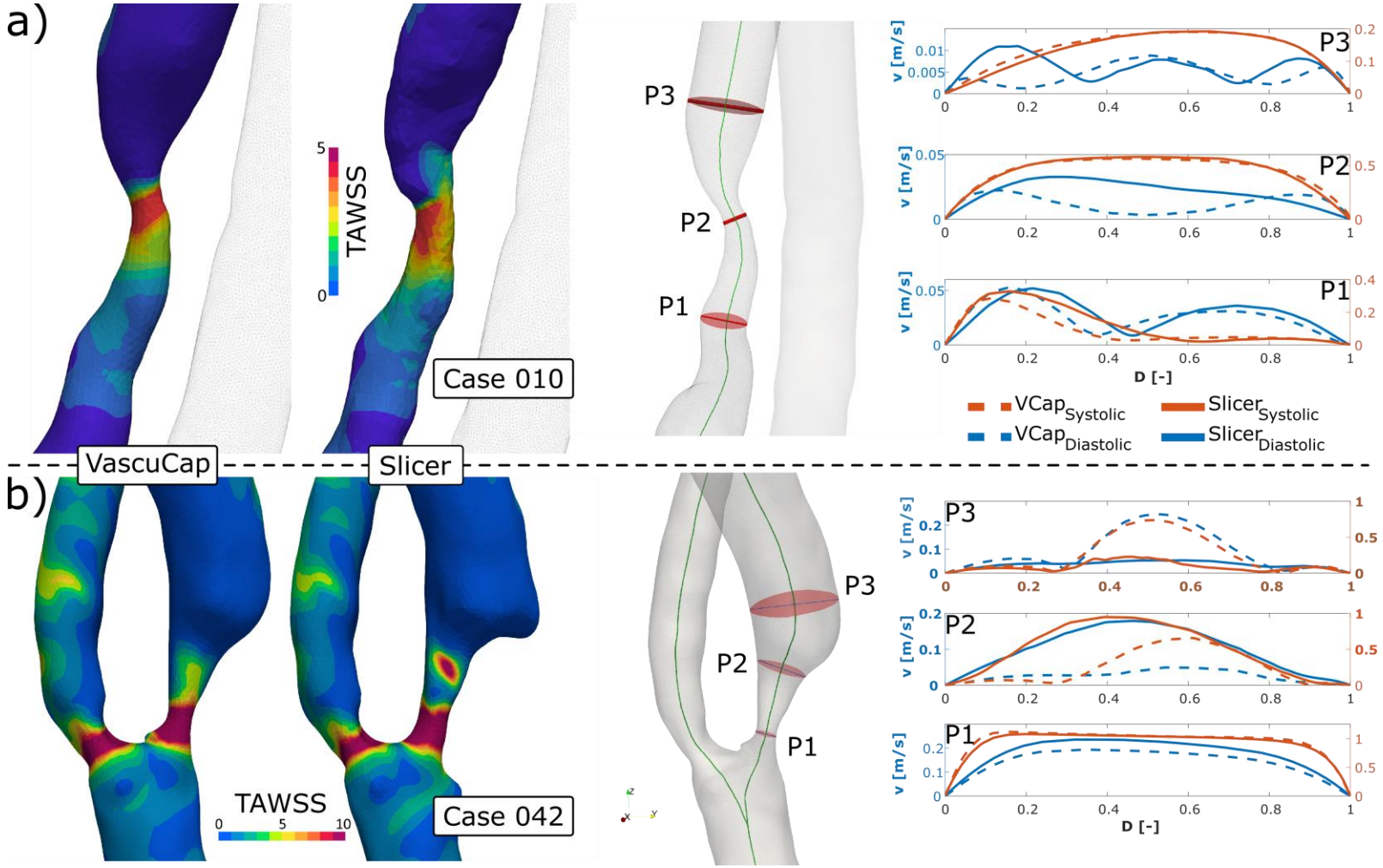




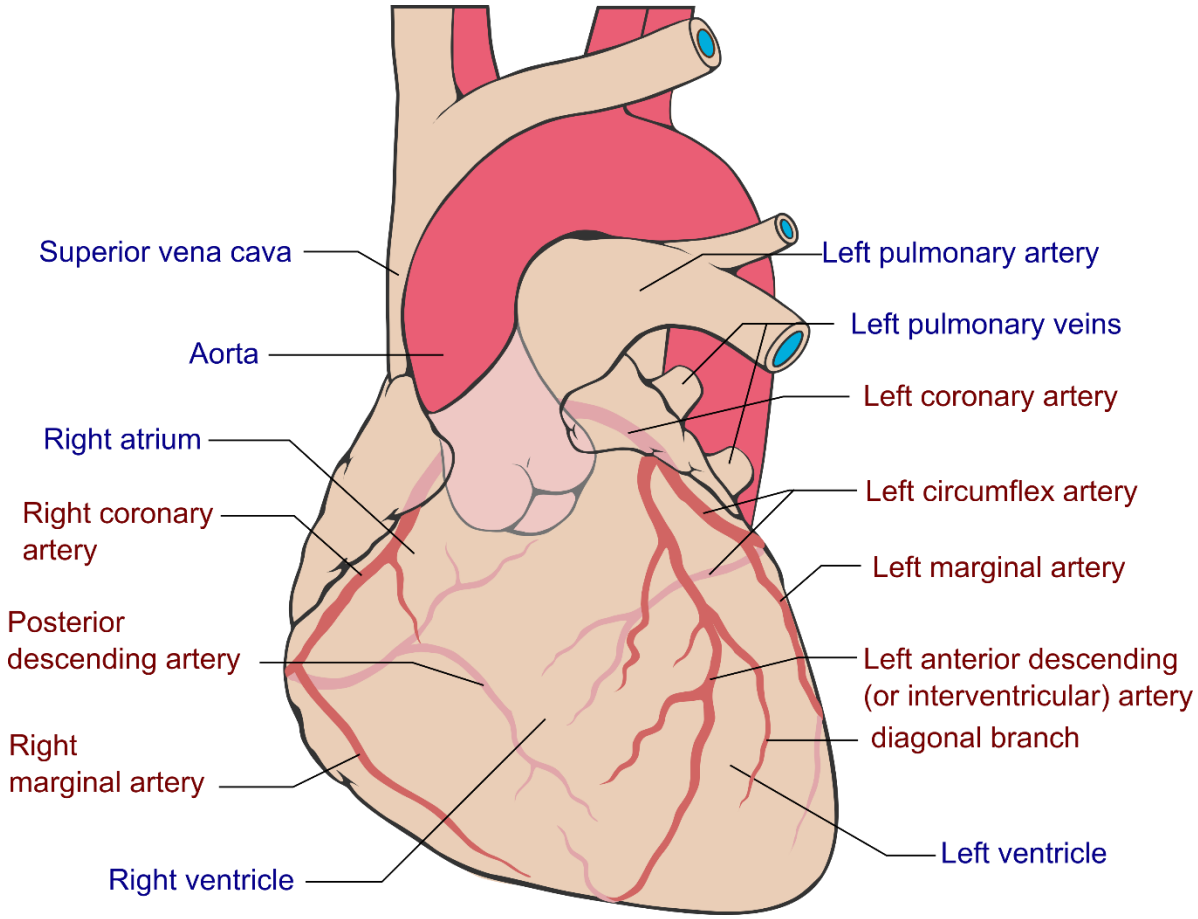


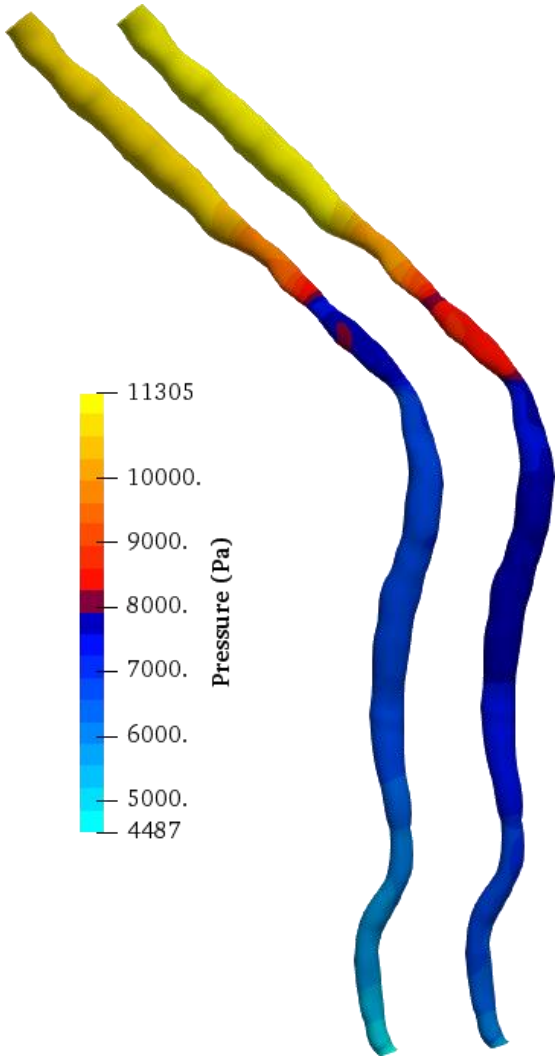
- Brain vessels
  - Stenosis
  - Aneurysms
    - Lateral or bifurcation
    - Rupture risk and initiation
  - Treatment simulation
    - Coiling
    - Flow diverter stents

Carotid bifurcation

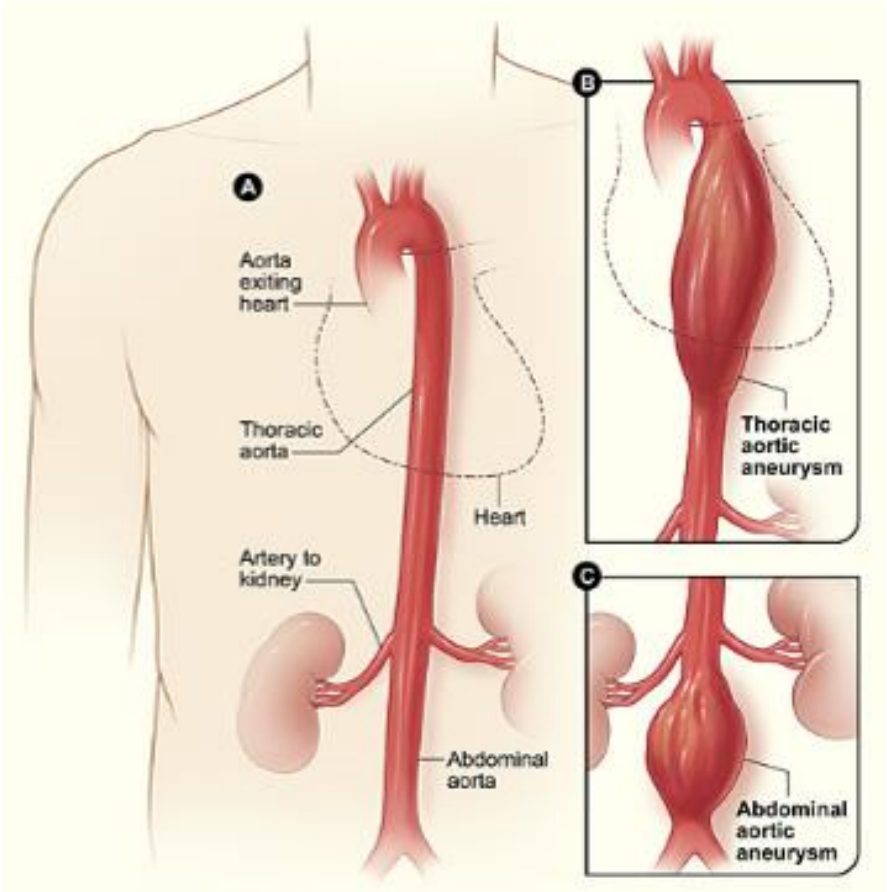


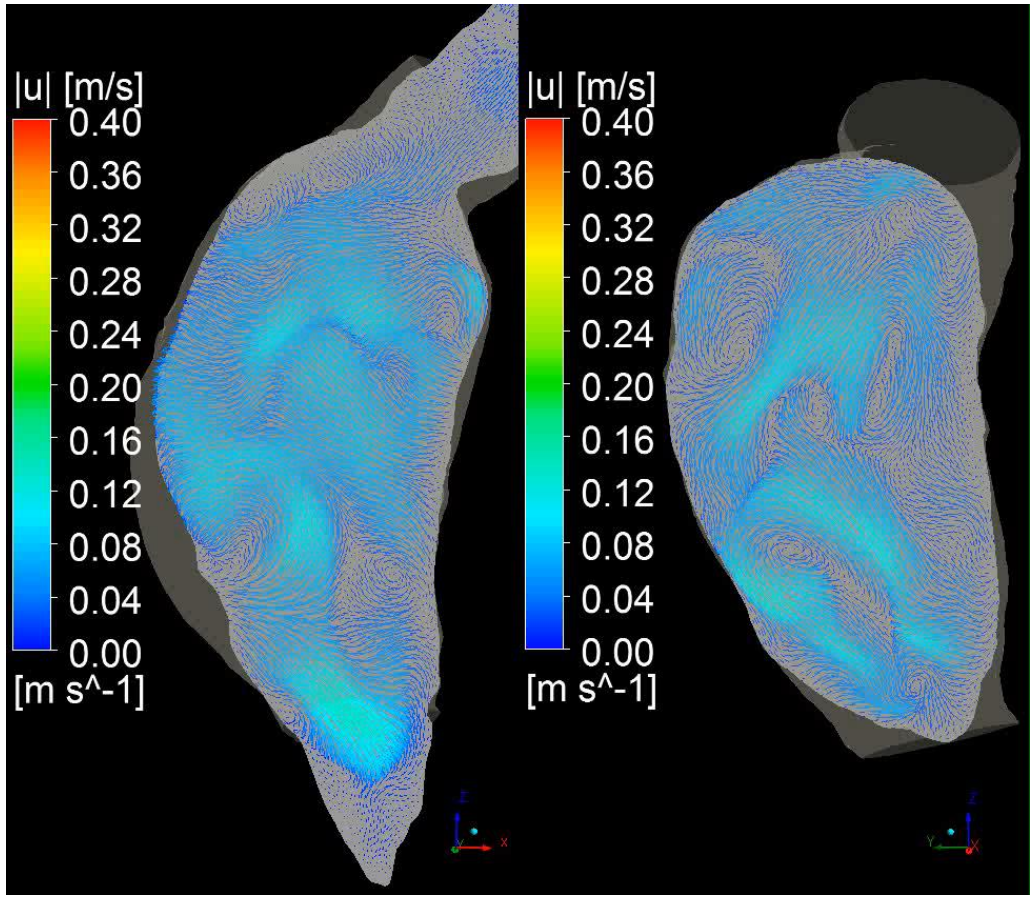
Coronary arteries





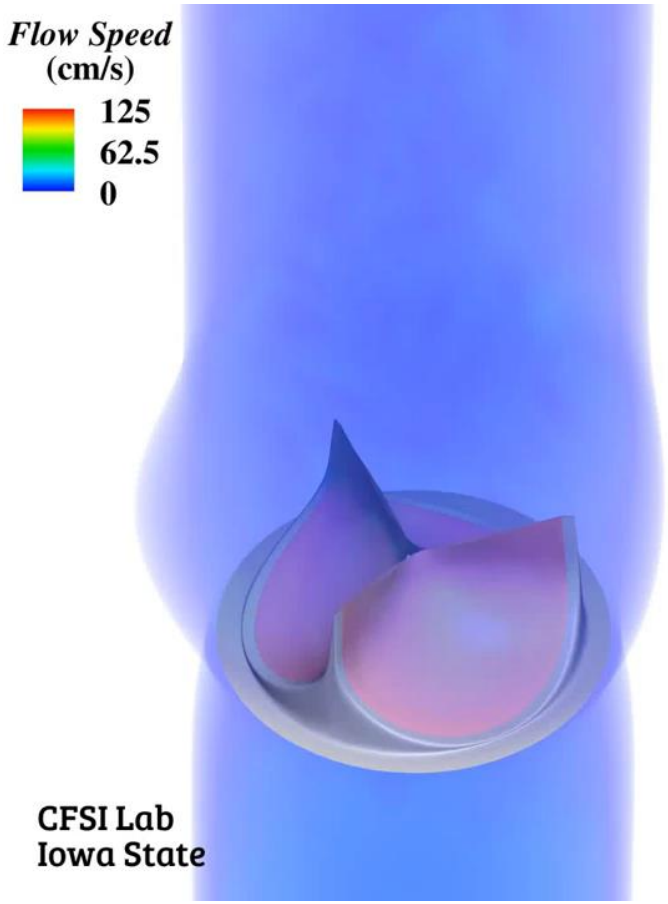
Abdominal aneurysms





Józsa et al. 2014 Journal of Heat and Fluid Flow

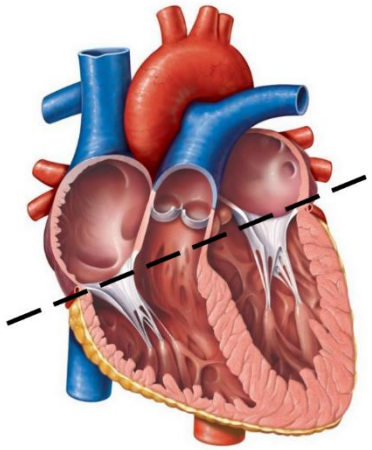
Aortic valves

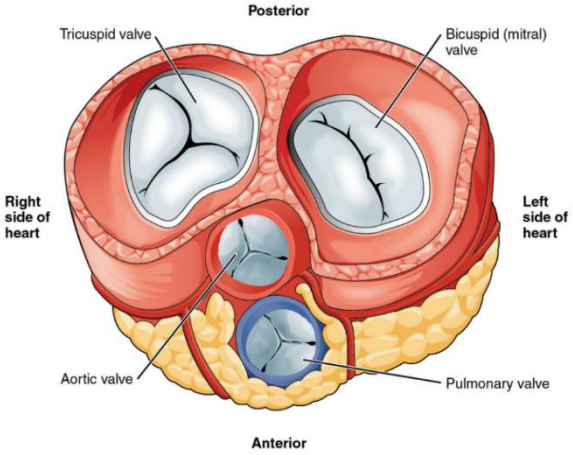


Hsu, MC., Kamensky, D., Xu, F. et al. Comput Mech (2015)

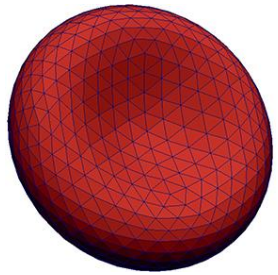
ImmersoGeometric method:

- Coupled Lagrangian and Eulerian modelling approach
- Nurbs based FEM solver for CFD
- Coupled Immerse boundary method



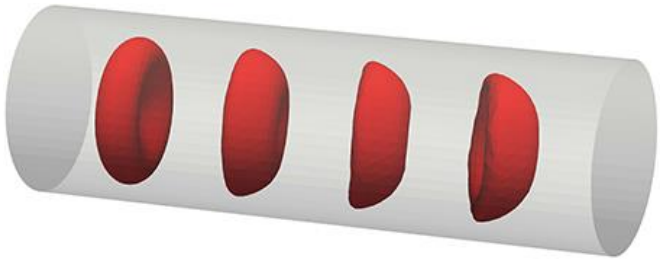


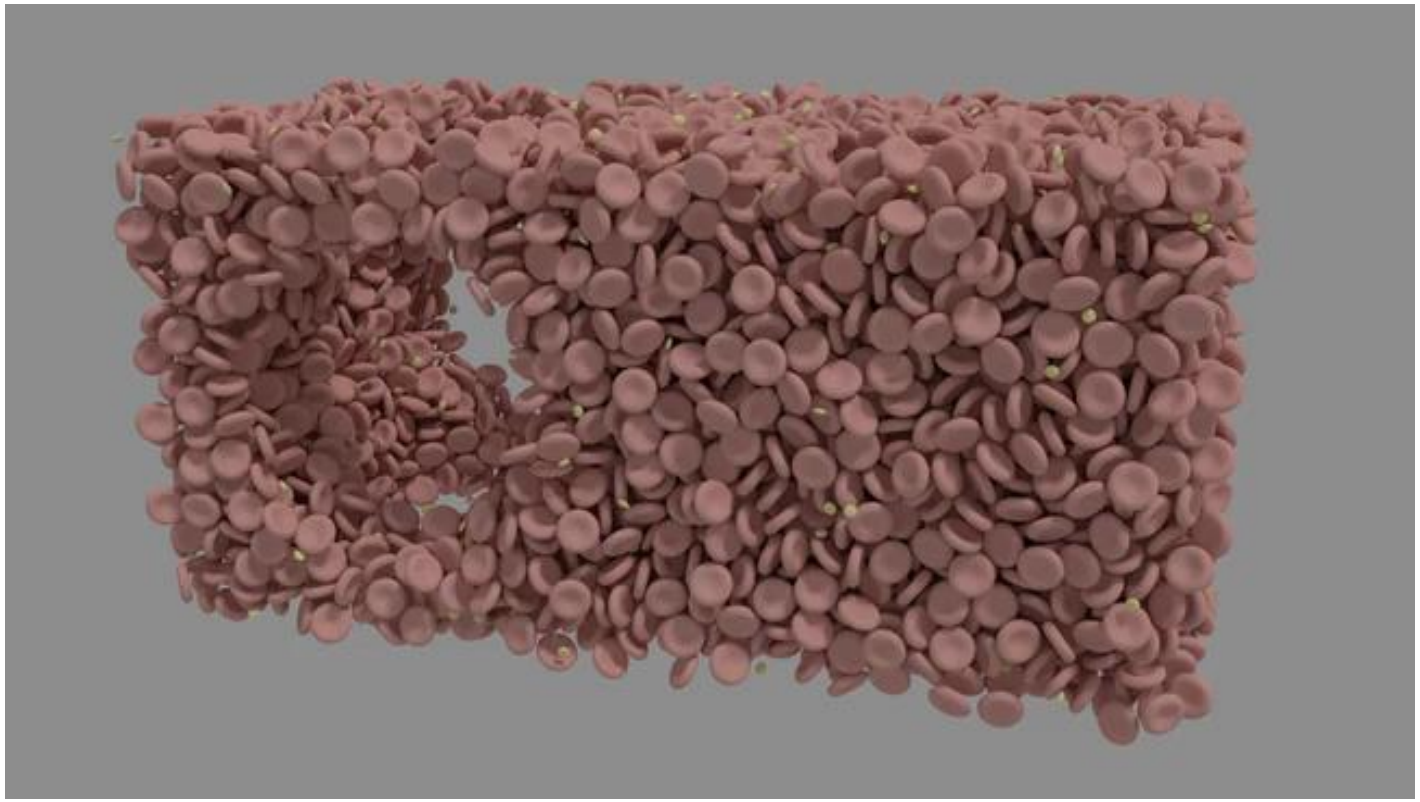
Blood cell dynamics



Red Blood Cell

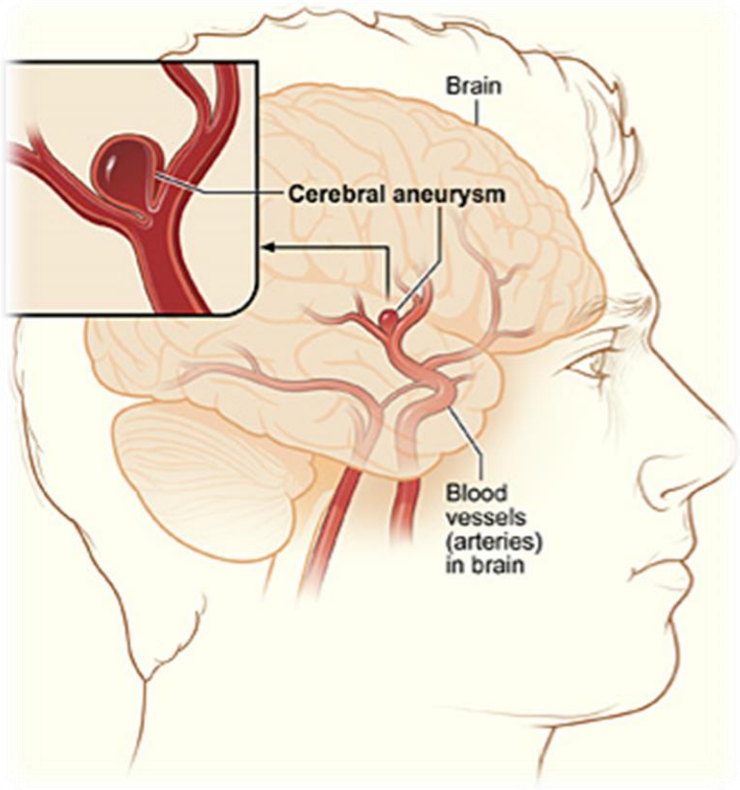
Platelet

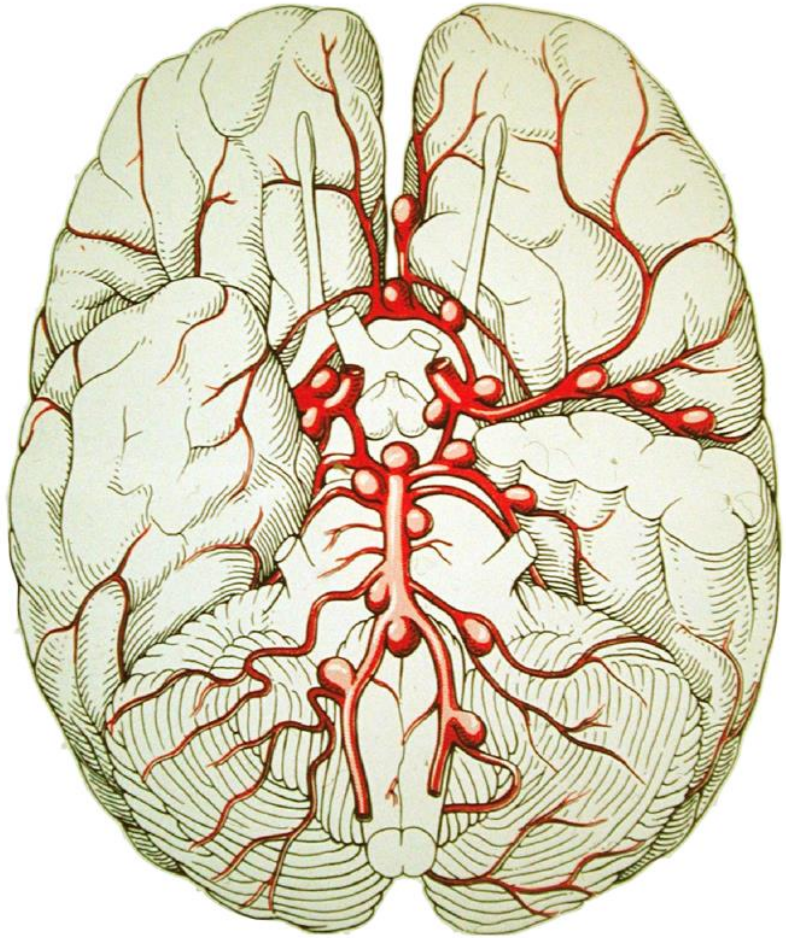




Zavodszky et al. Frontiers in physiology 2017

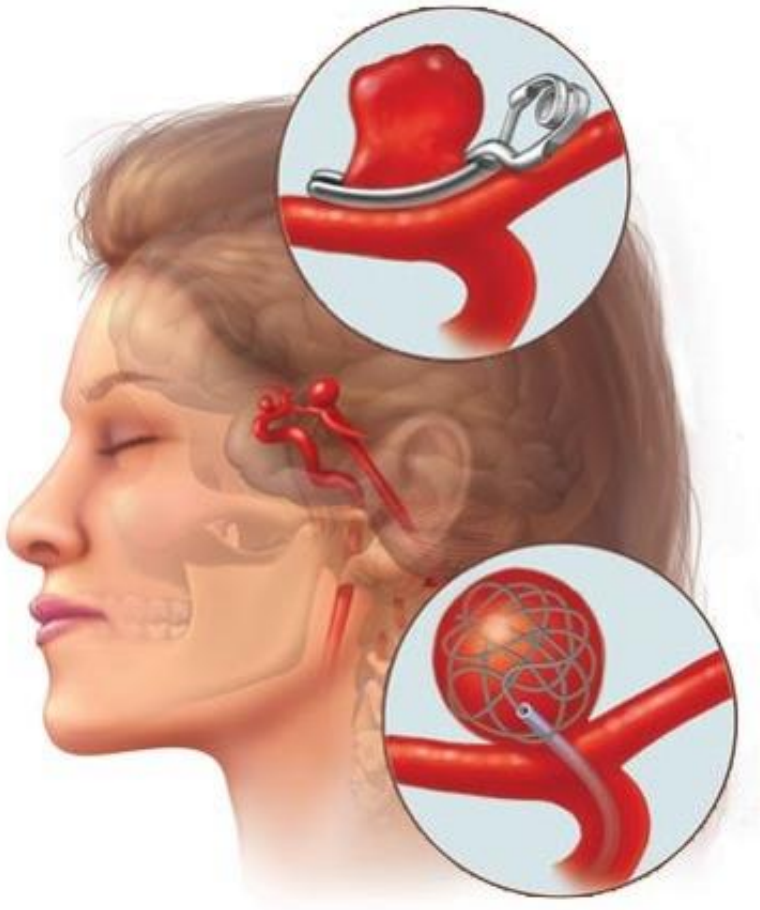
Brain aneurysms





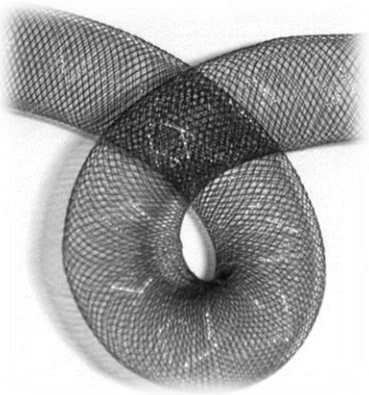
Treatments

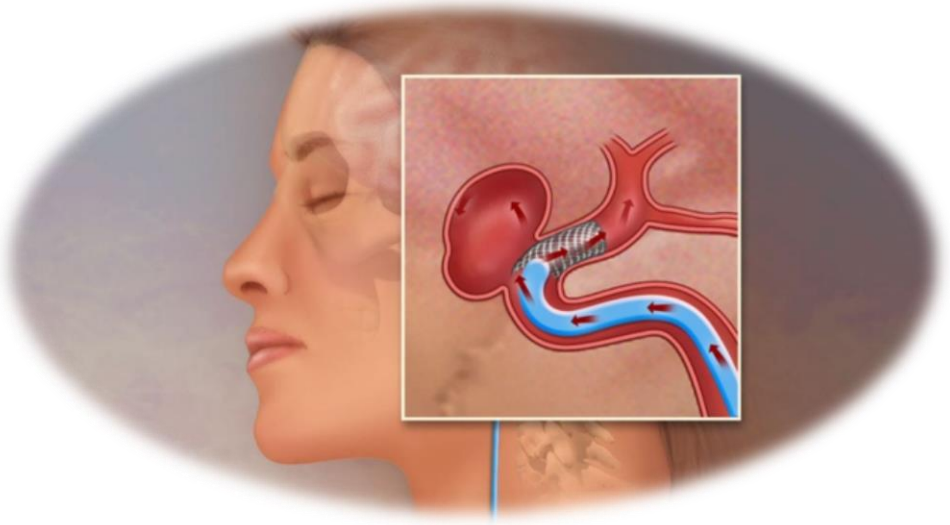
Clips



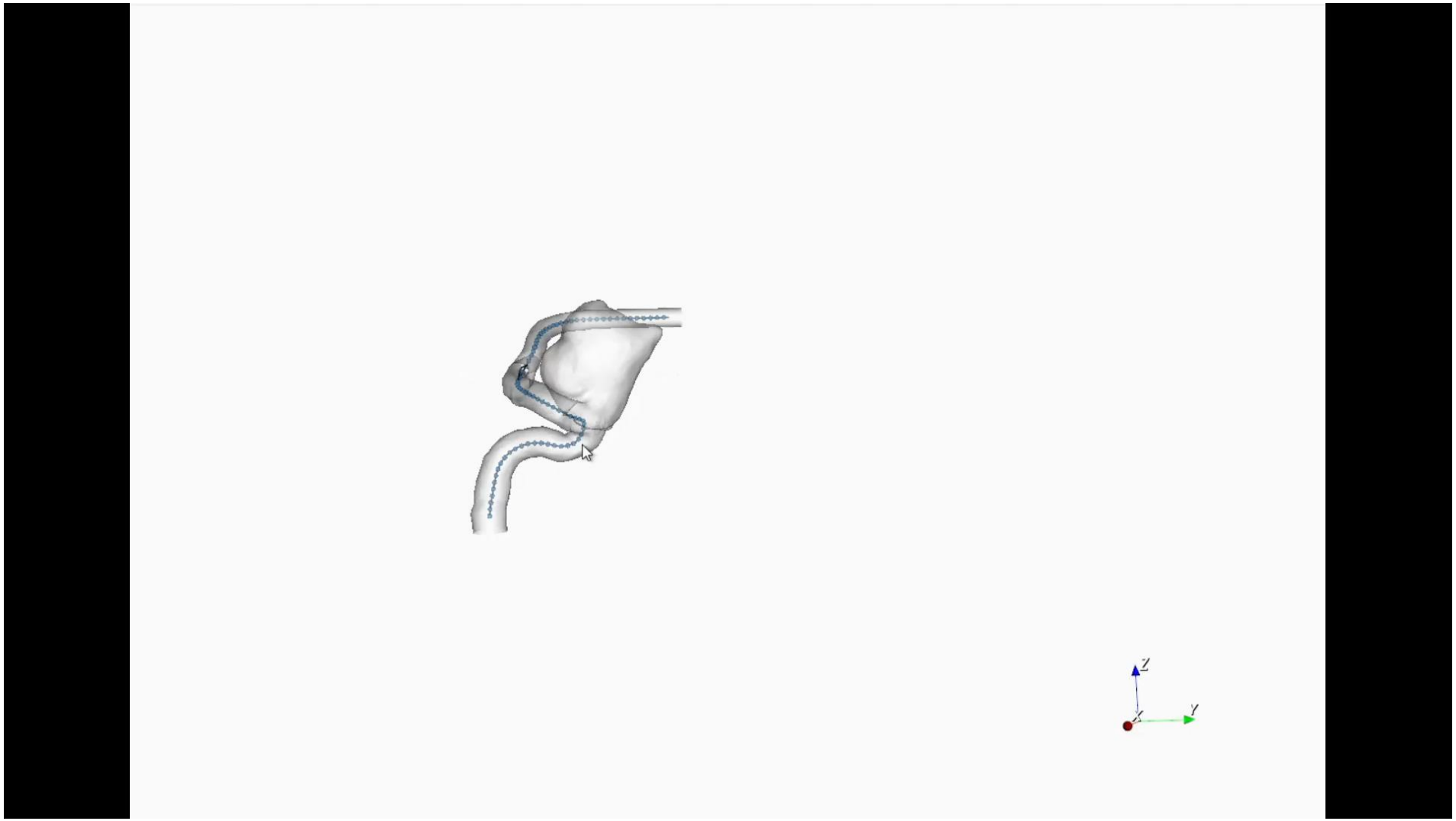
Coil

Flow diverter stent





Treatment analysis



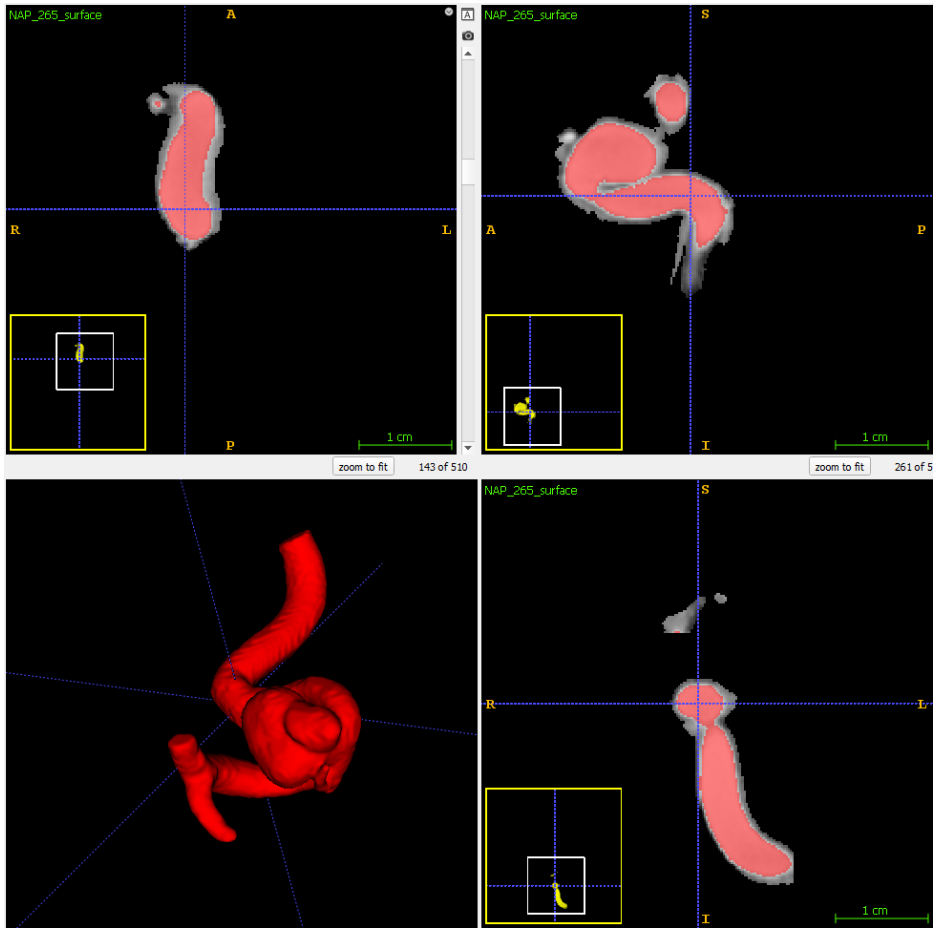
Department of Hydrodynamic Systems

3D CFD simulations

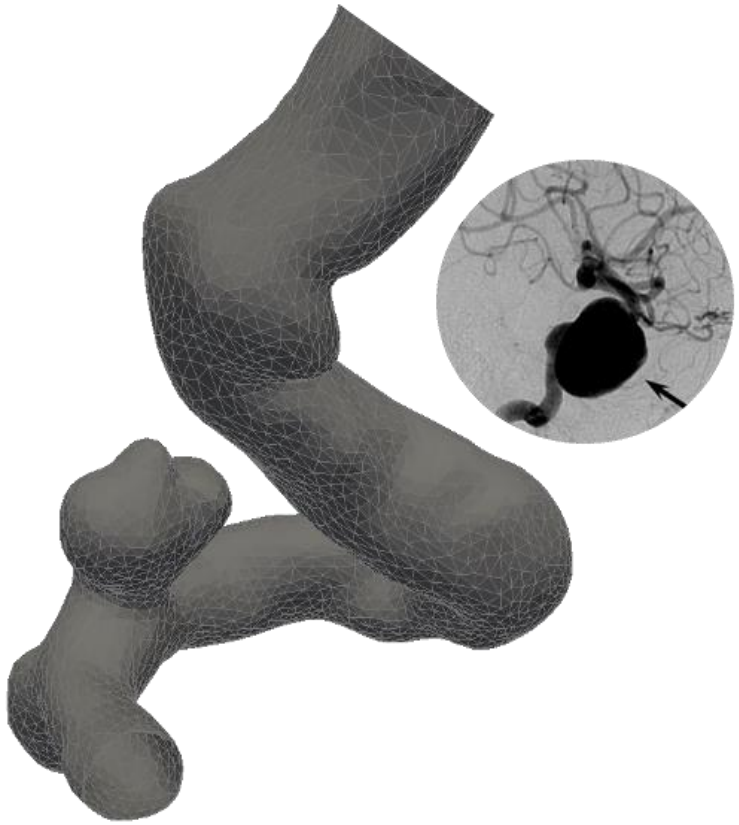
Pre-processing and simulation

- Numerical meshing
- Numerical method
- Turbulence modelling
- Artificial or realistic geometry?
- Generic or patients specific BC's?
- Rheology?
- Rigid or elastic wall?

Medical imaging



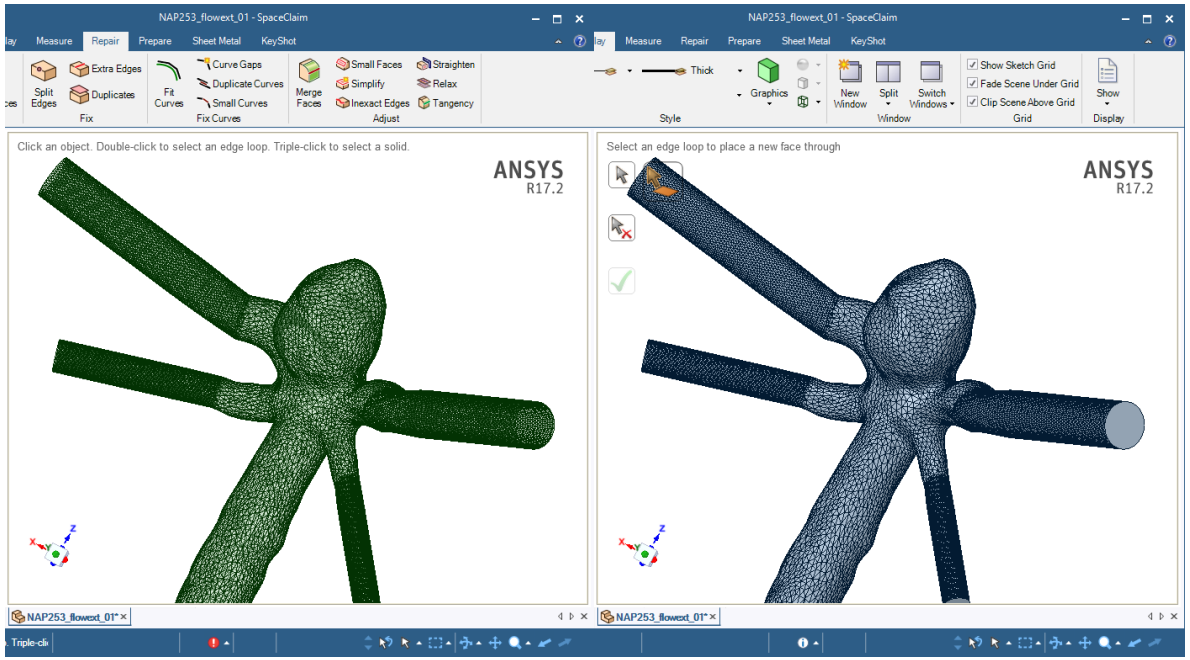
Segmentation

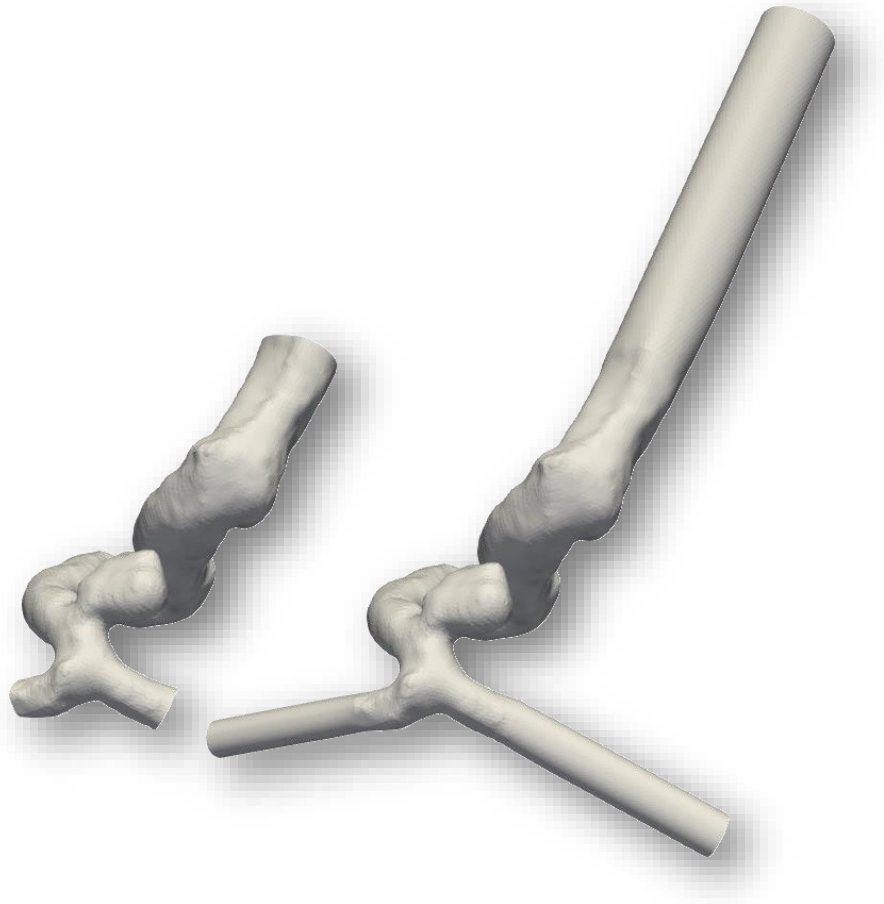


Surface smoothing

Numerical meshing

- Surface mesh preprocessing
  - Extensions!
- Volume geometry creation
  - SpaceClaim, ICEM, GMSH, FreeCad…

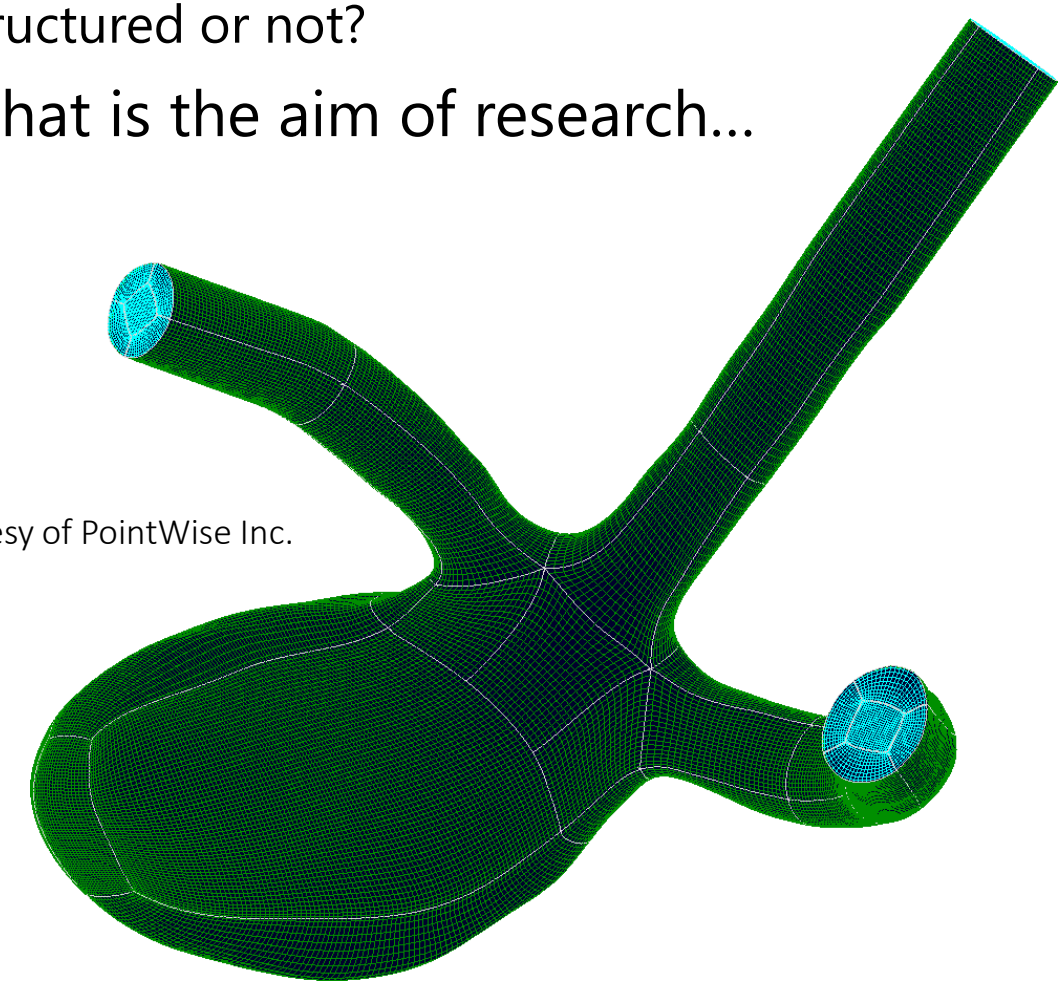




Numerical meshing

Structured or not?

What is the aim of research…



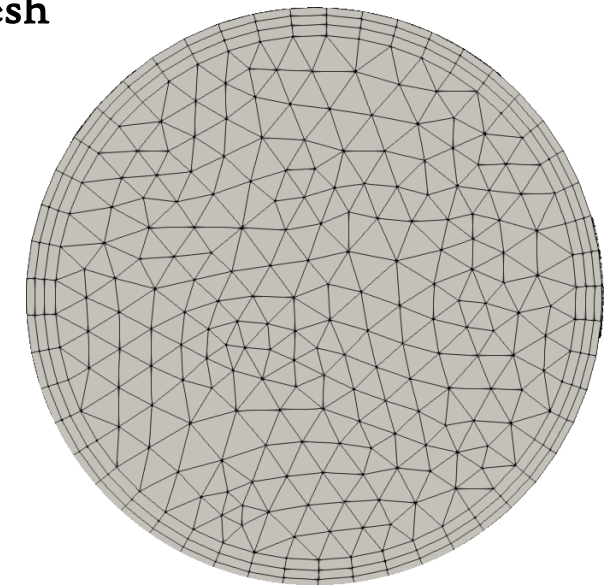
Courtesy of PointWise Inc.

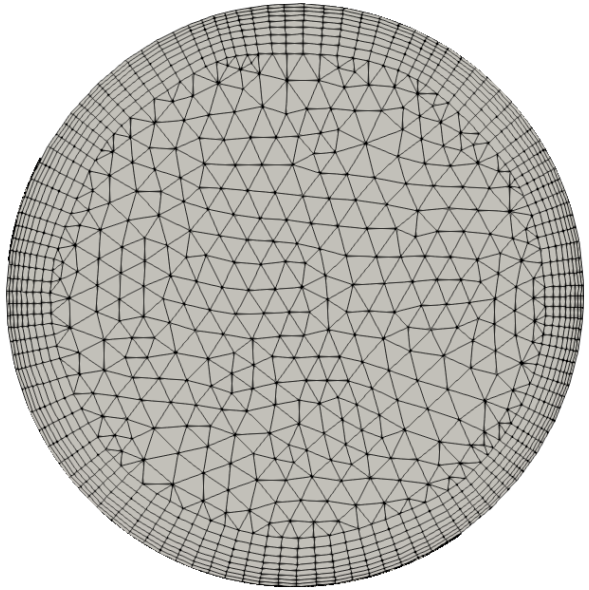
Numerical meshing

- Influence of mesh resolution
    1. Velocity profiles
    2. Wall shear stress
    3. Pressure drop

- Element size
- Number of boundary layers

Course mesh





Fine mesh

Numerical methods

- Finite volume method(FVM)
  - *Traditionally used (change in directions)*
  - *Fluent, CFX, OpenFOAM, StarCCM, …*
- Finite element method (FEM)
  - Abaqus, Fenics
- Smooth particle Hydrodynamics (SPH)
  - *Xflow, Panormus*
- Lattice – Boltzmann Method (LBM)
  - *Palabos, OpenLB …*
- Integrated solvers and
  - *SimVascular, Oasis(Fenics),*
  - *Heartflow,…Vascutreat (HemoFlowCFD)*

Ansys

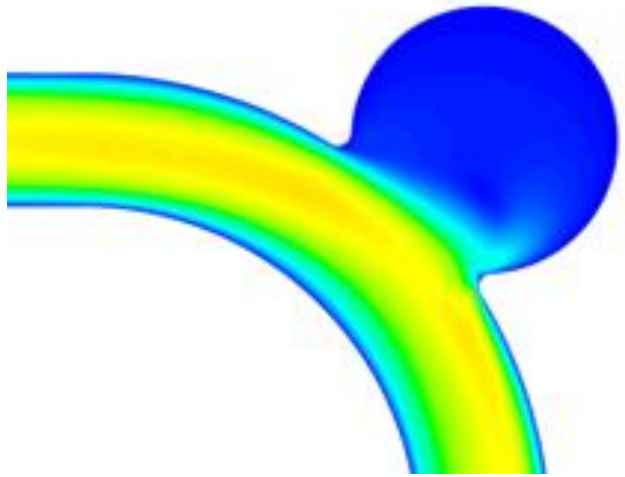
OpenFOAM®

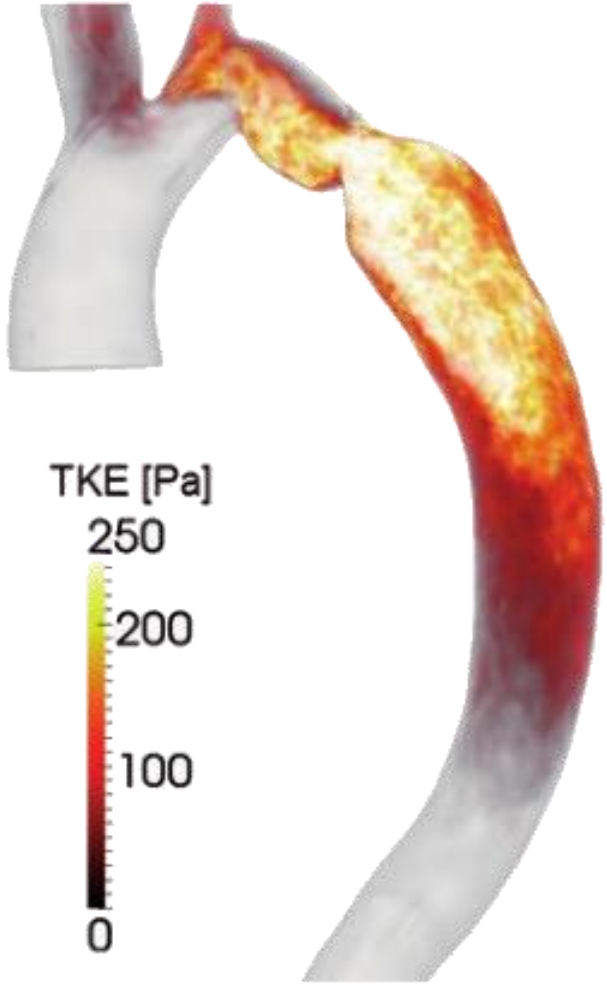
FENICS PROJECT

SimVascular

Pre-processing and simulation

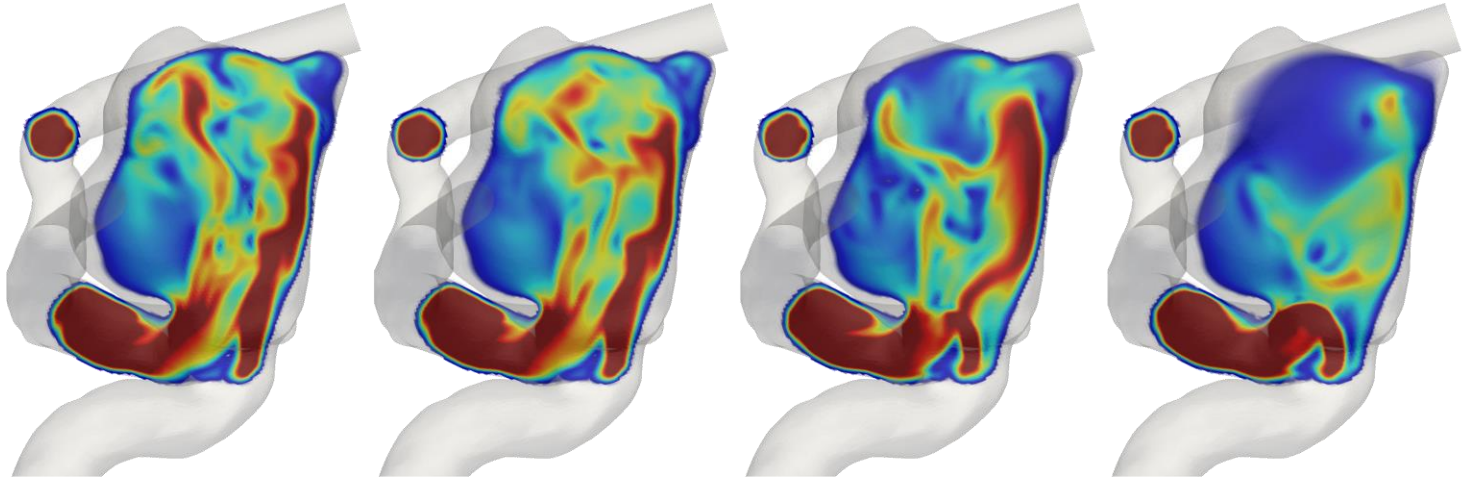
- Turbulence????
- Aorta
  - Might be transitional or fully turbulent
  - High Re
- Brain vessels and coronary arteries
  - Low Re
- Carotid bifurcation
  - Moderate Re



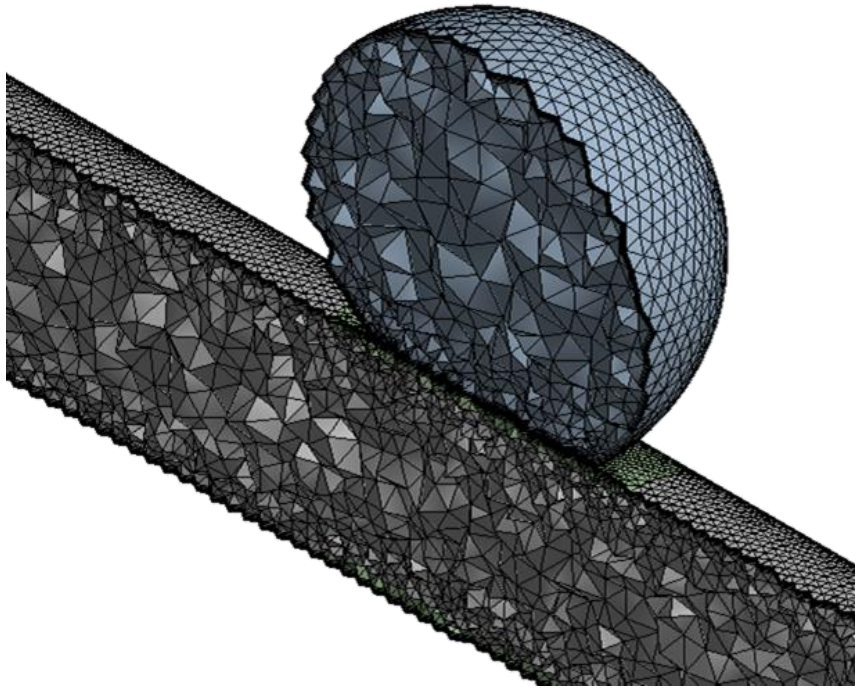


Pre-processing and simulation

Realistic



Artificial geometry



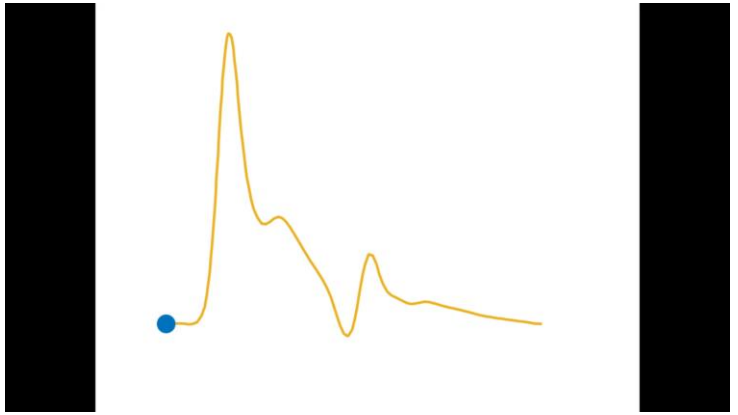
Boundary conditions

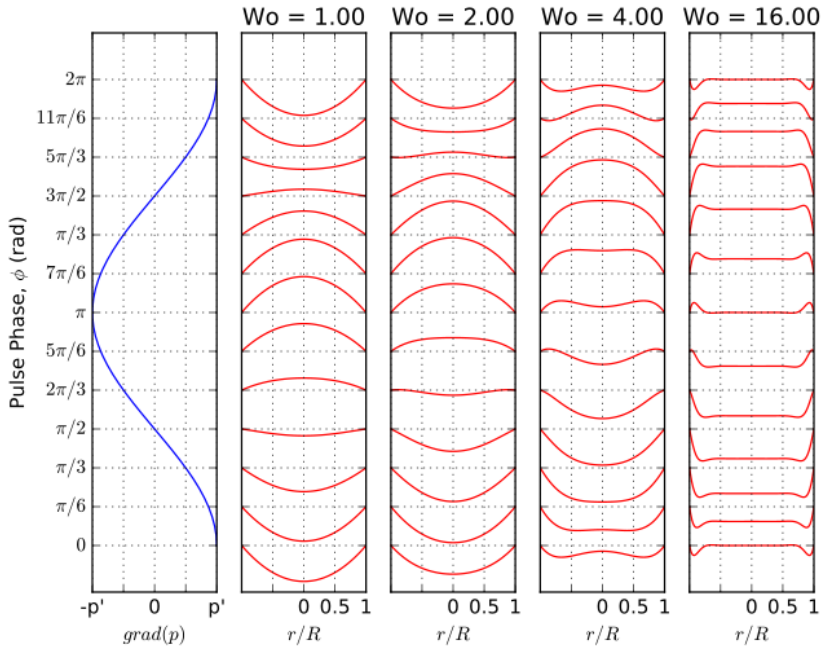
- Constant BCs
- Paraboloid velocity profile with time varying amplitude
- Pressure waveform (problems)!
- Wommersley profile

$$u(r,t)=\frac{2q_0}{\pi R^2}\left[1-\left(\frac{r}{R}\right)^2\right]+\sum_{n=1}^{N}\frac{q_n}{\pi R^2}\left[\frac{1-\dfrac{J_0(\beta_n\, r/R)}{J_0(\beta_n)}}{\dfrac{2J_1(\beta_n)}{\beta_n J_0(\beta_n)}}\right]e^{in\omega t}$$

$$\beta_n = i^{3/2}R\sqrt{\frac{n\omega}{\nu}} = i^{3/2}\sqrt{n}\alpha$$

α – Wommersly number





So after all…

The basic workflow:

1. Image processing with caution!
    1. Segmentation & Smoothing
2. Numerical mesh generation
    1. Aim of the research
    2. Boundary layer assesment
3. Modelling approach
    1. Numerical methods (discretization, convergence, …)
    2. Boundary conditions (waveforms…)
    3. FSI, additional equations (Biology…)
    4. Coupling (0D-3D; 1D-3D)

Thank your for your attention!

Benjamin Csippa

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Videos

Brain Aneurysms And Blood Flow Dynamics

https://www.youtube.com/watch?v=ncAWnWOhdfI&t=25s

CompBioMed Virtual Humans Film

https://www.youtube.com/watch?v=1FvRSJ9W734&t=7s