

Numerical Simulations of Blood Flow in the Left Atrial Appendage: Investigating the Influence of Anatomical Shapes

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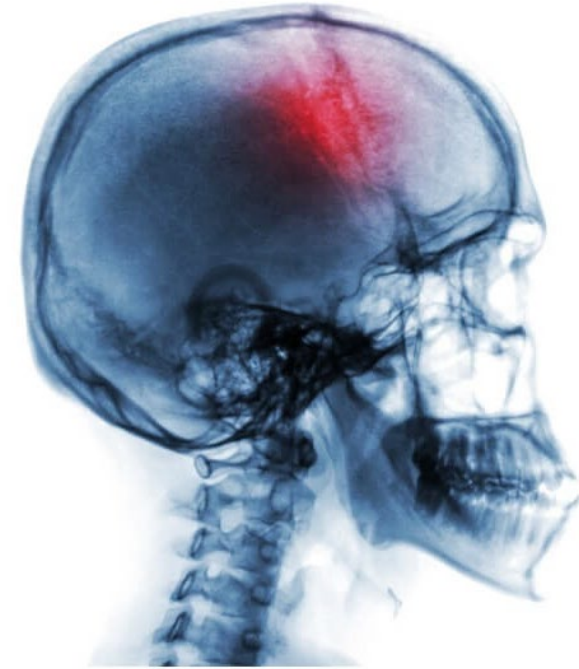
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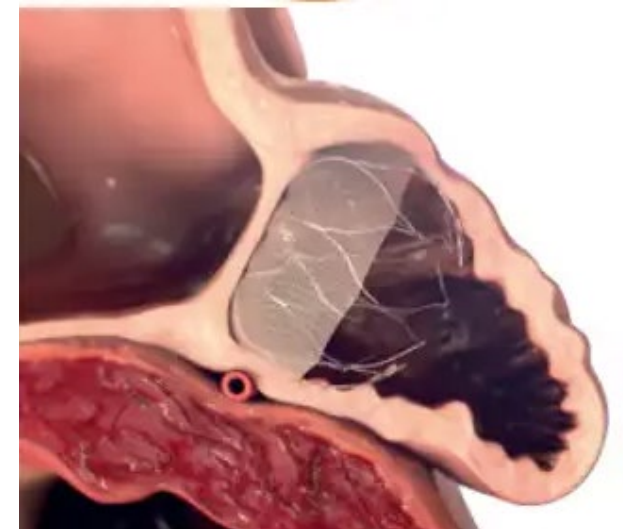
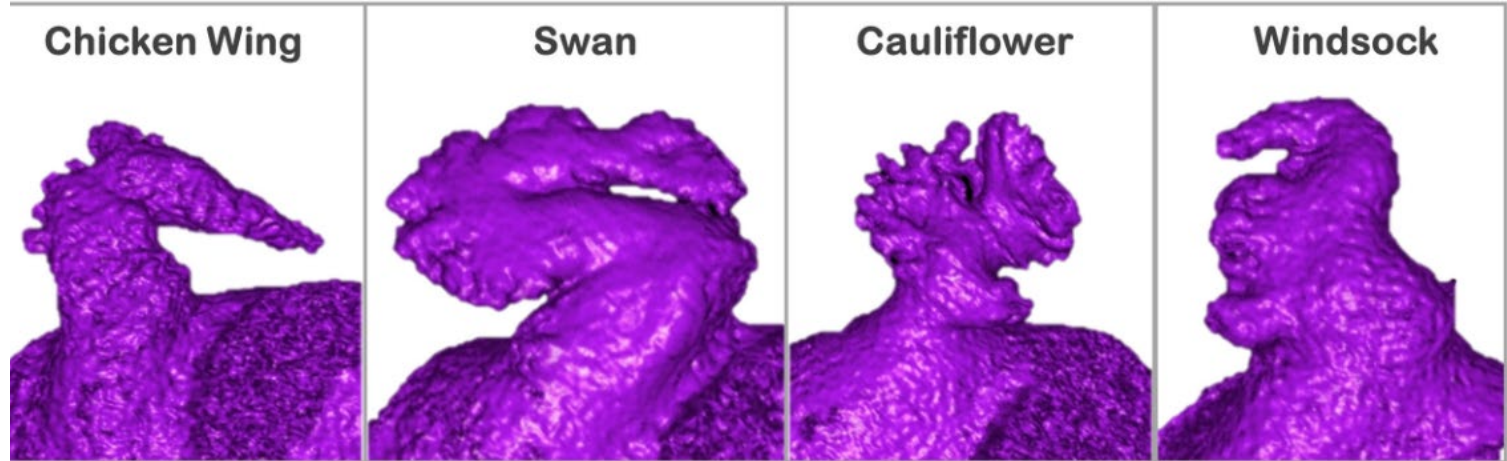
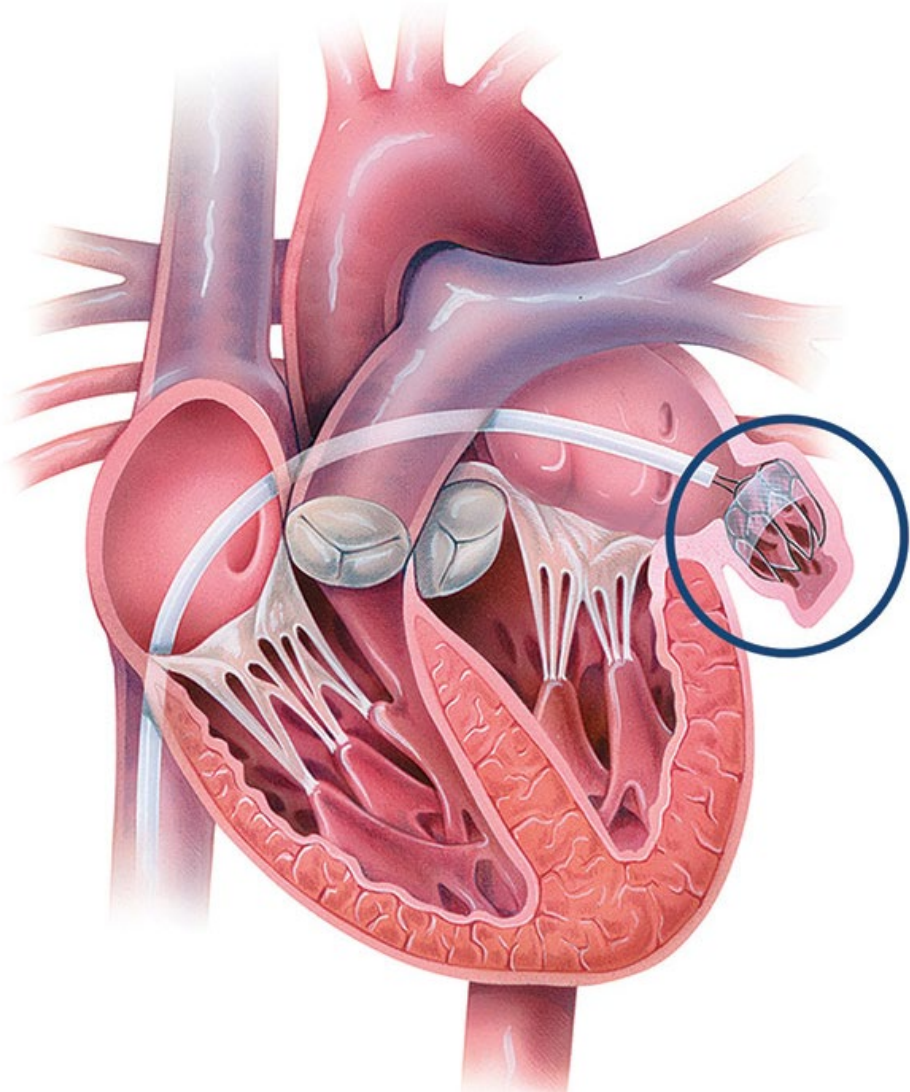
Atrial Fibrillation (AF)

- Atrial fibrillation (AF) - most common cardiac arrhythmias
- Average lifetime risk of **25 %**
- High risk (**4 %**) of thromb formation => brain stroke
 - **91 %** of strokes come from **left atrial appendage (LAA)**

- Anticoagulant drugs or LAA closure

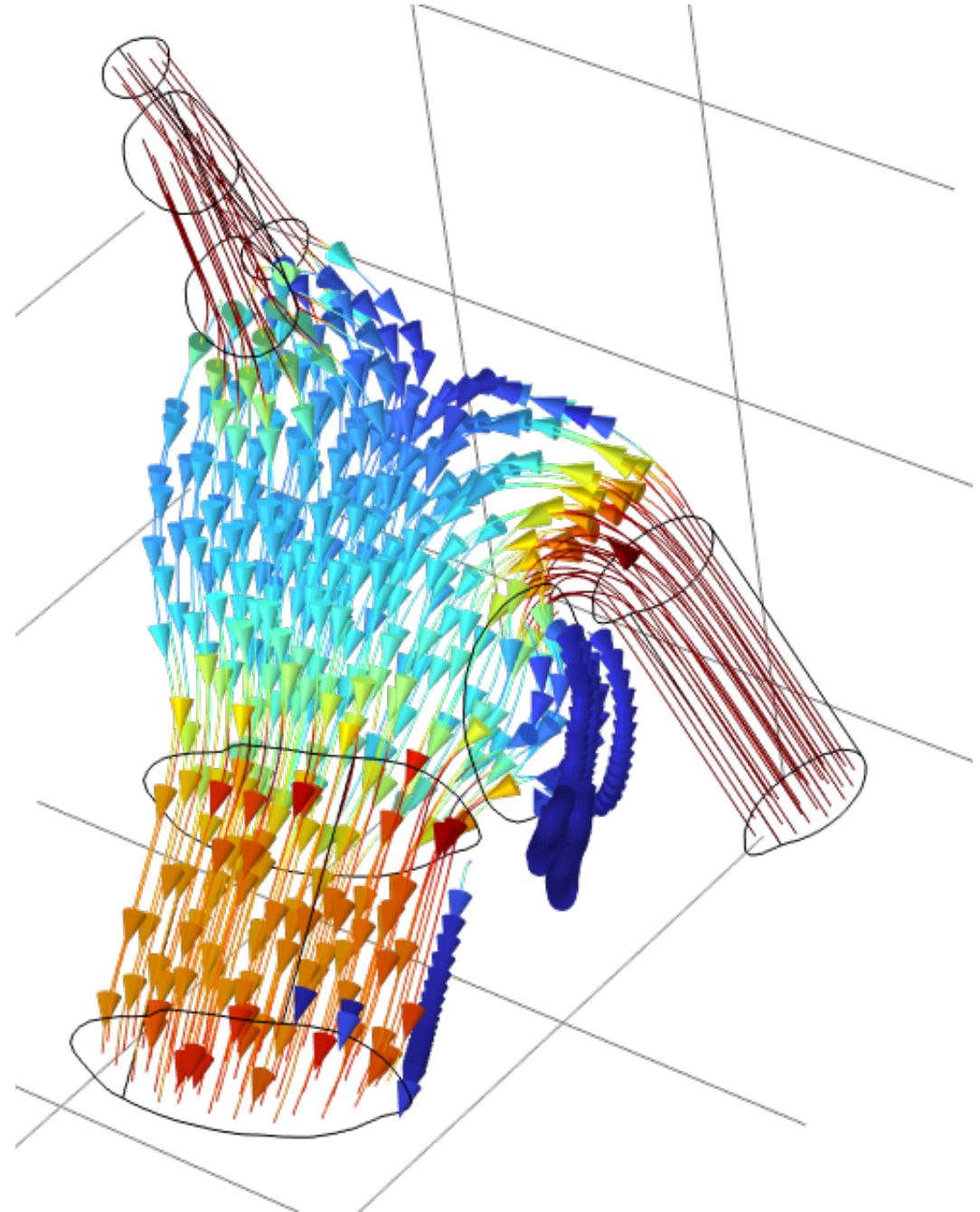


Left Atrial Appendage (LAA)



Goal of Feasibility Study

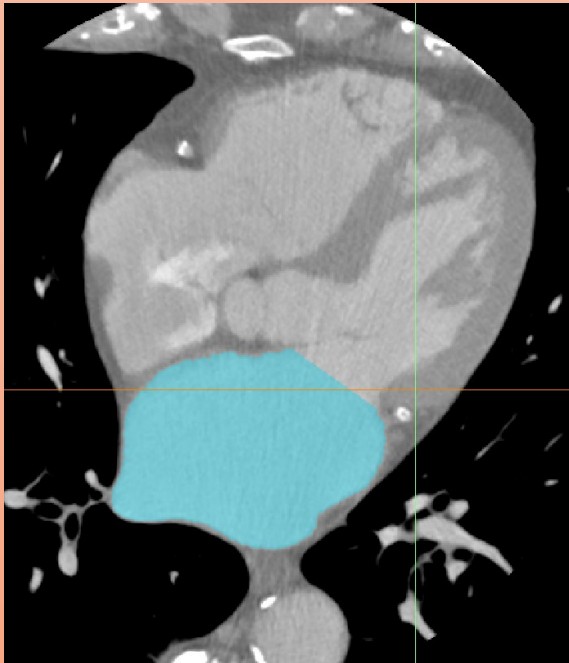
Investigate whether the anatomical structures of the left atrium influence the rate of blood flow in LAA.



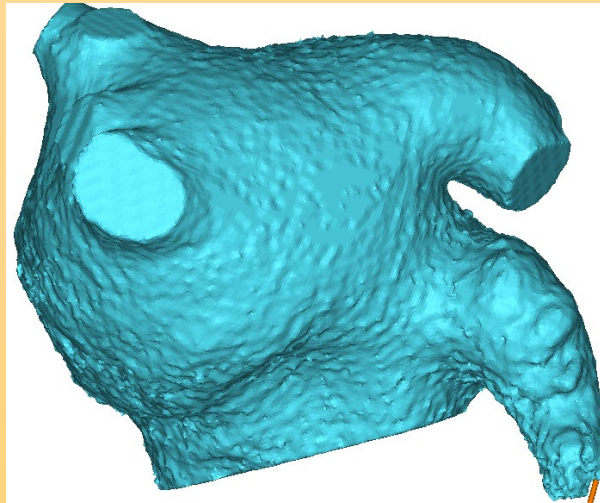
Heart Model Creation

- CT or MRI images in **good quality**
- Import mesh in COMSOL Multiphysics

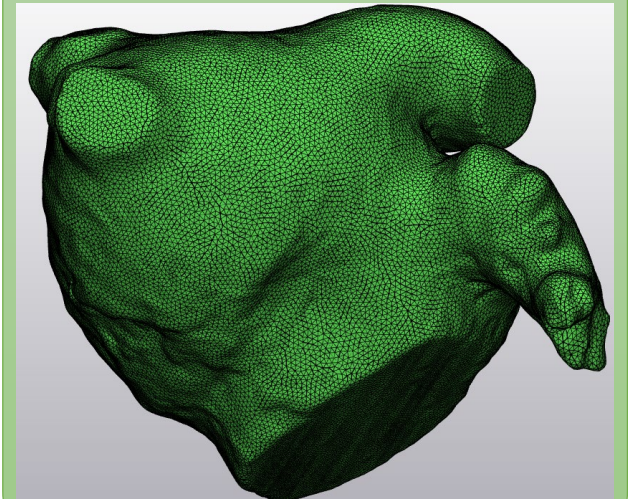
Model segmentation



Geometry adjustment

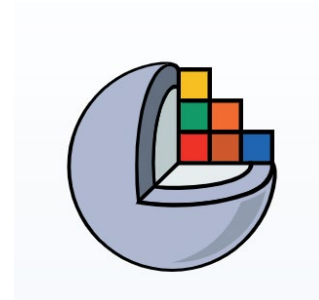


Mesh creation



Segmentation Software

- 3D slicer (Open source)
 - Strong community
- iSeg (Zurich Medtech)

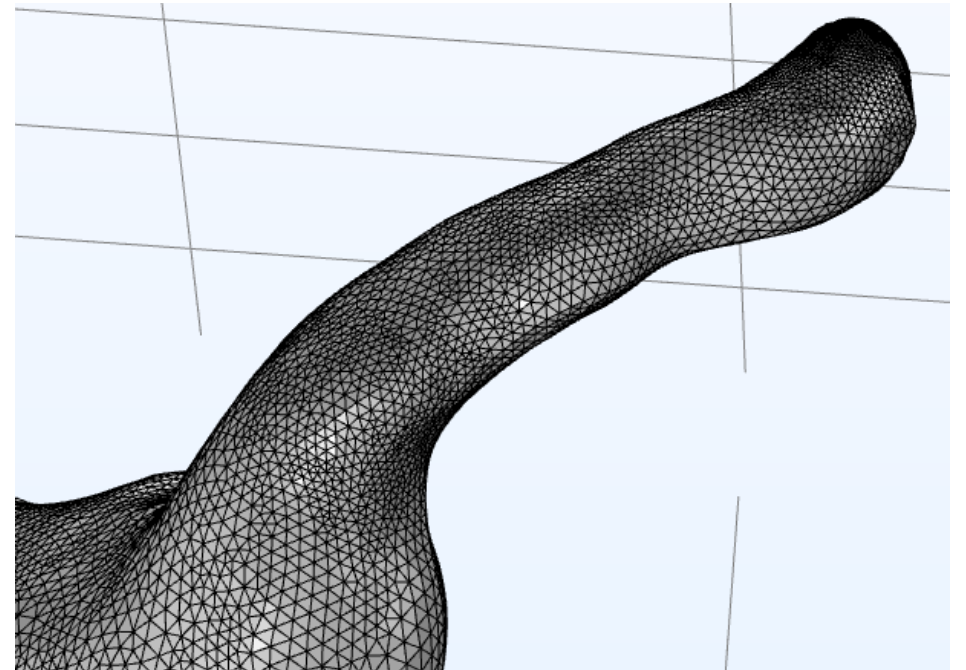
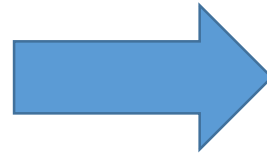
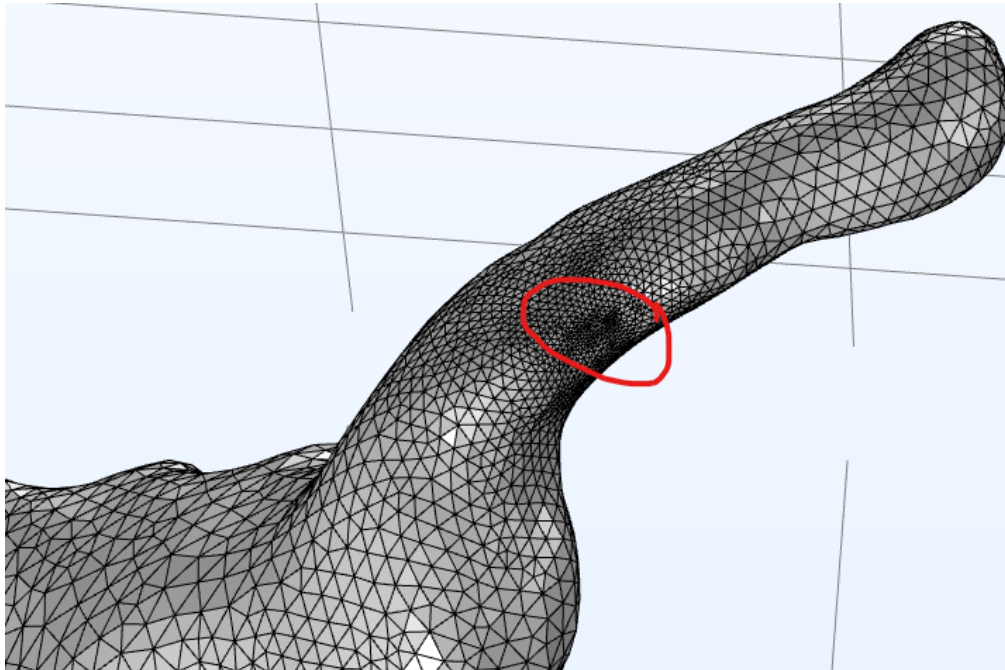


- Mimics (Materialise)



Mesh Improvement

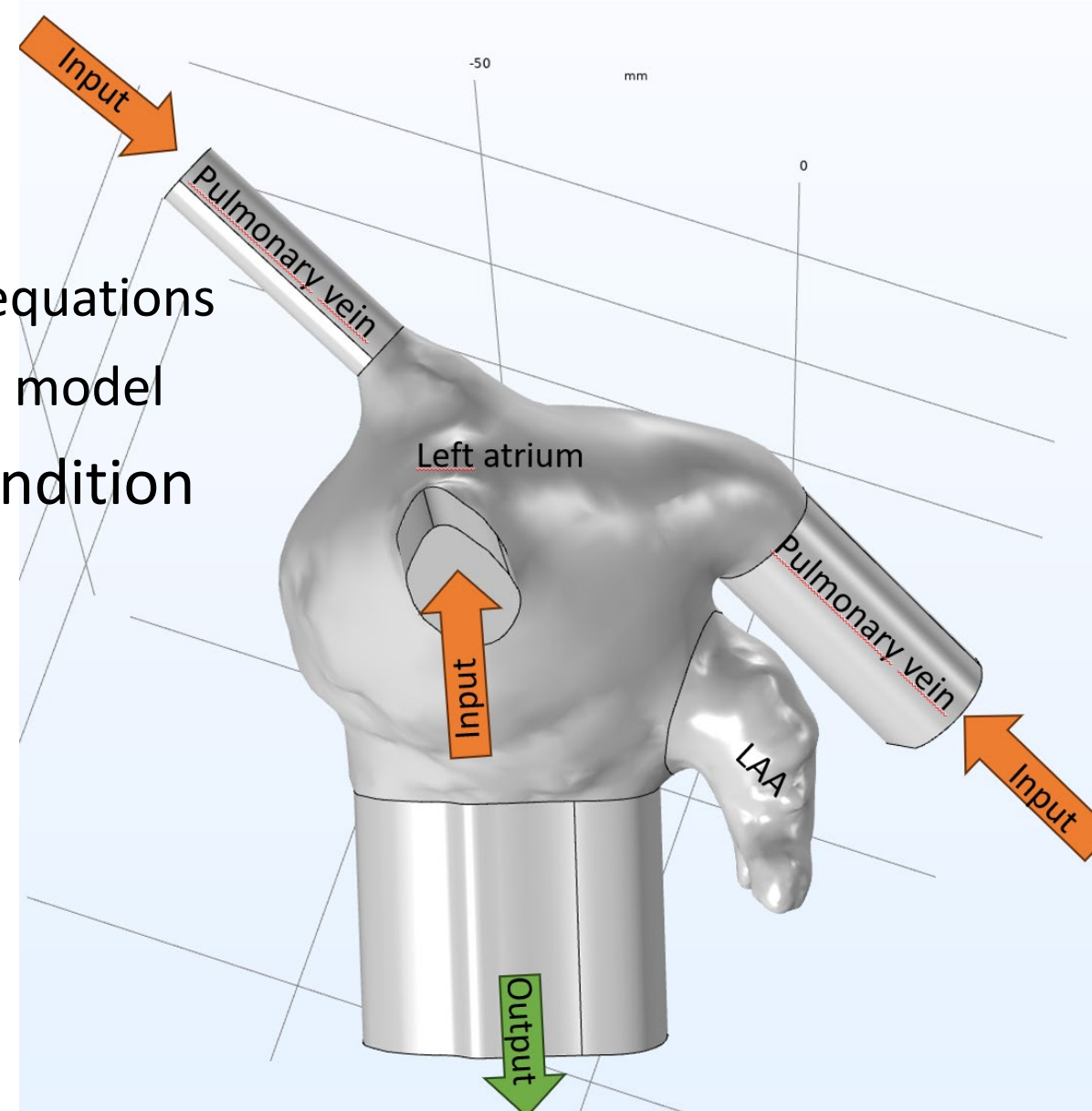
- Mesh import + improve mesh in COMSOL 6.1



Model Settings

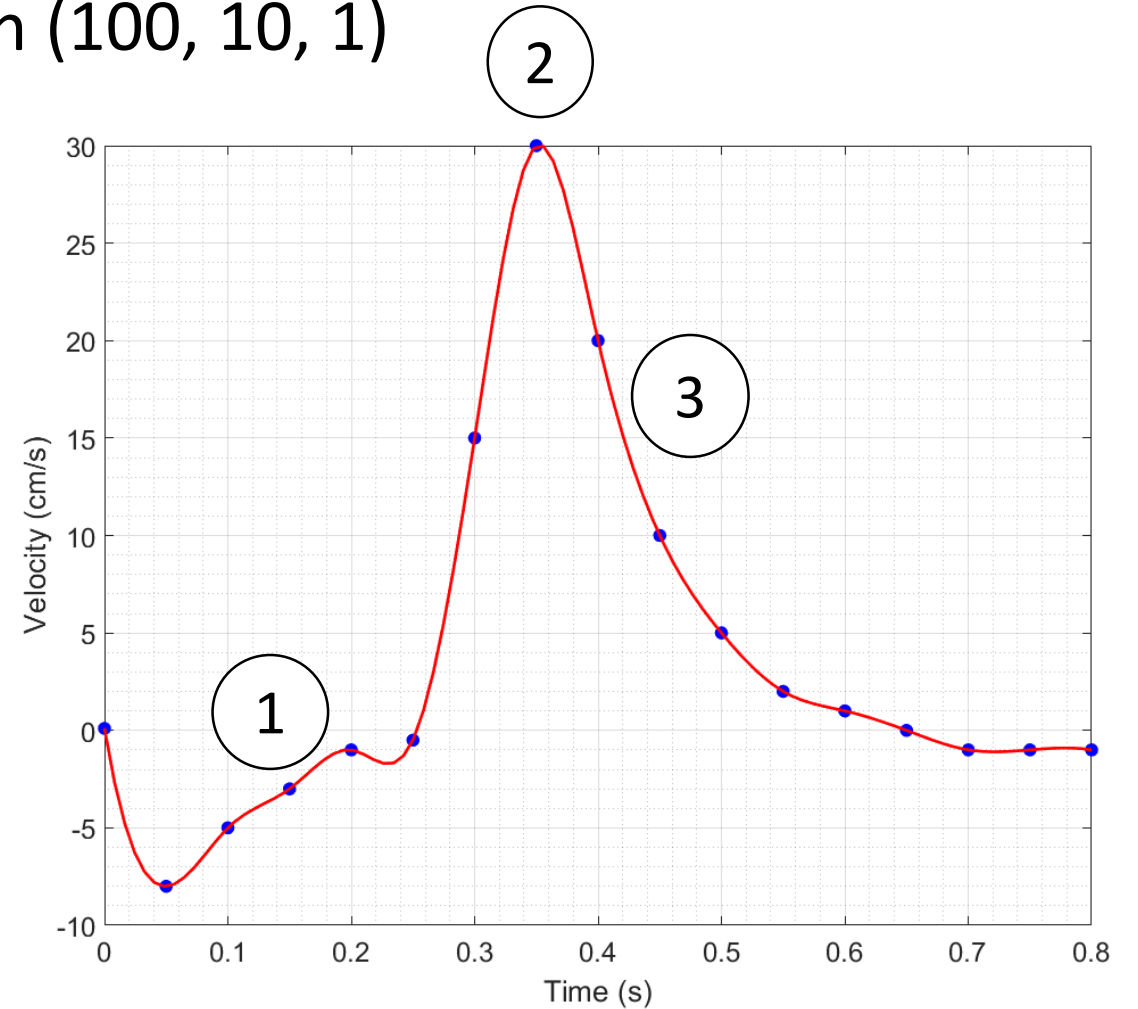
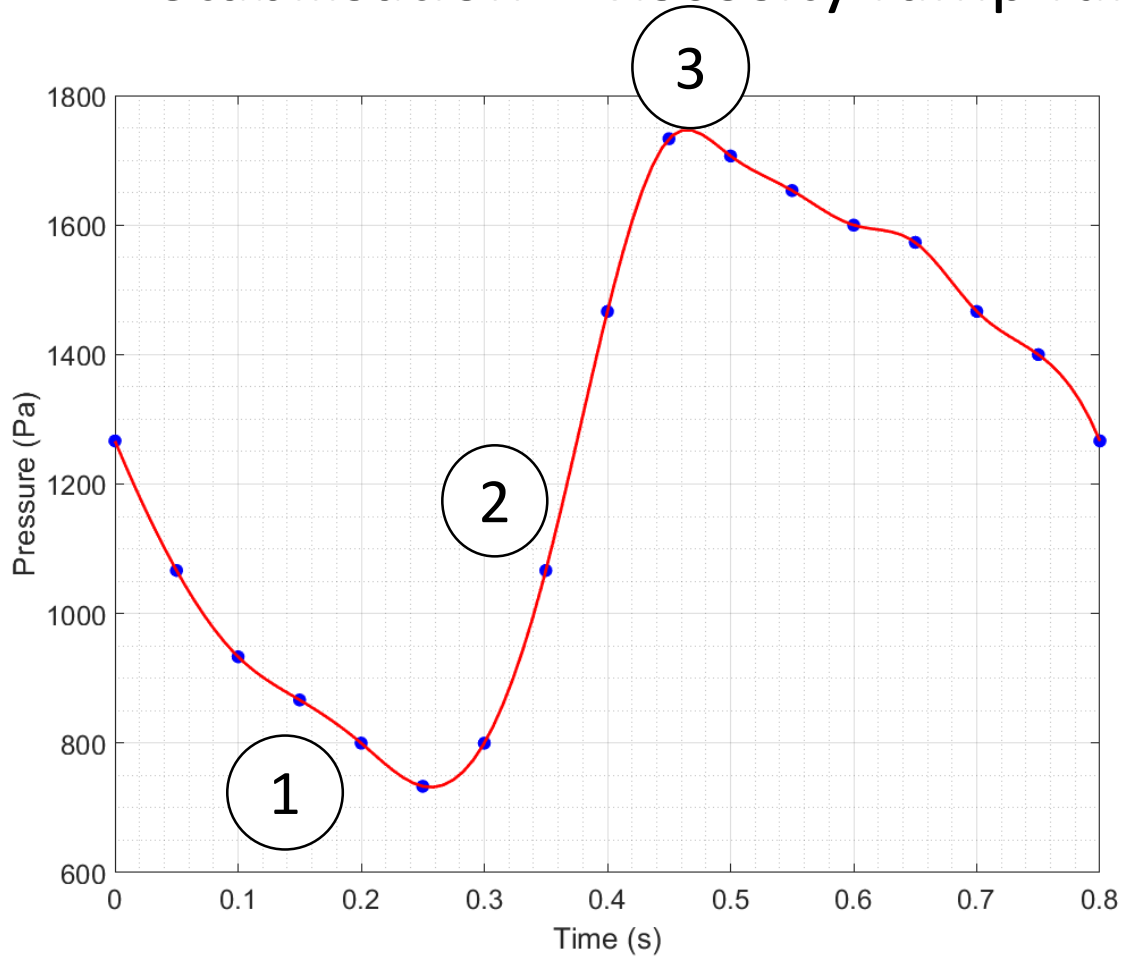
- Extrude inlets and outlets
- CFD Turbulent flow physics – blood flow
 - Reynolds-Averaged Navier-Stokes“ (RANS) equations
 - Shear Stress Transport“ (SST) turbulent CFD model
- Input (4x pulmonary veins) - pressure condition
- Output - velocity condition
- Simulation of one heart cycle (0.8 sec)

Blood parameters	
Viscosity	0.035 (P·s)
Density	1060 (kg·m ⁻³)



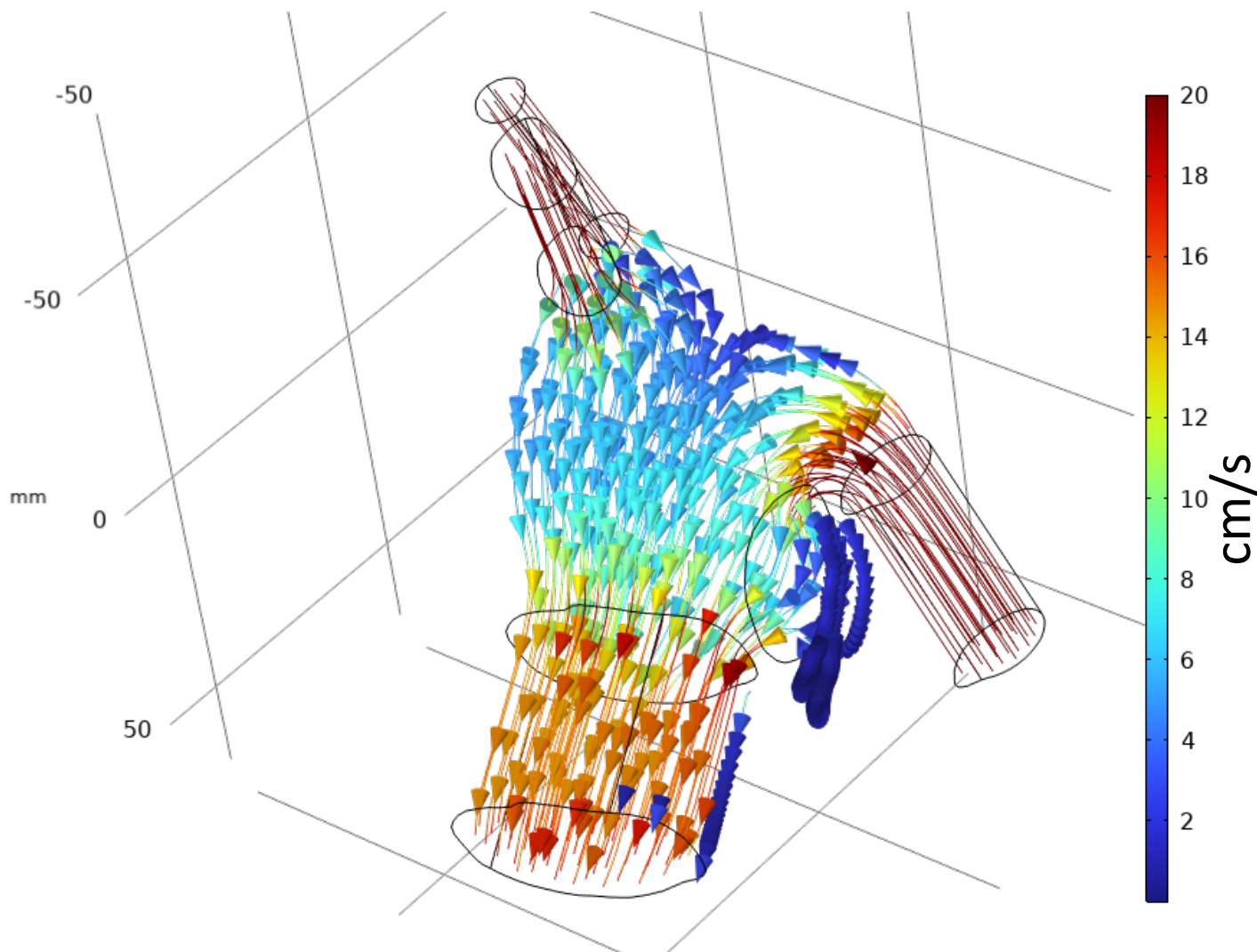
Model Settings

- Time dependent simulation
- Stabilisation – viscosity ramp function (100, 10, 1)

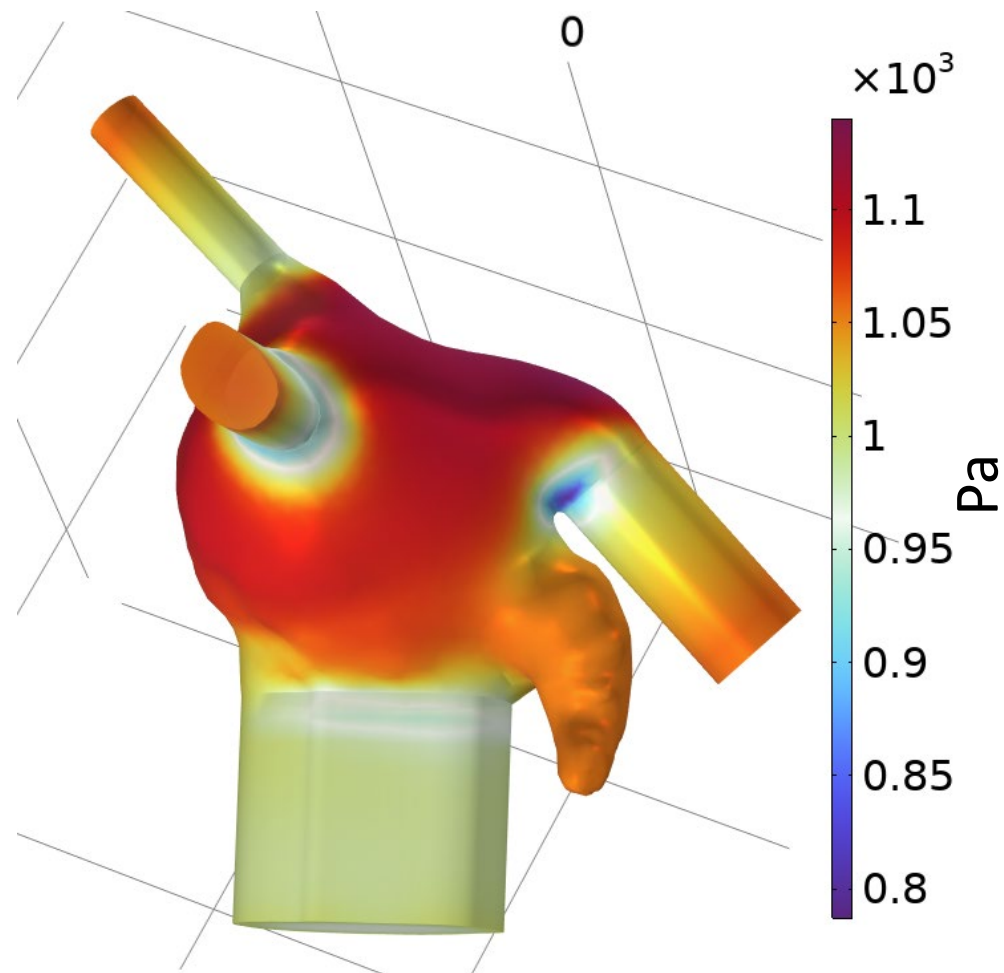


Results Analysis

Blood flow velocity



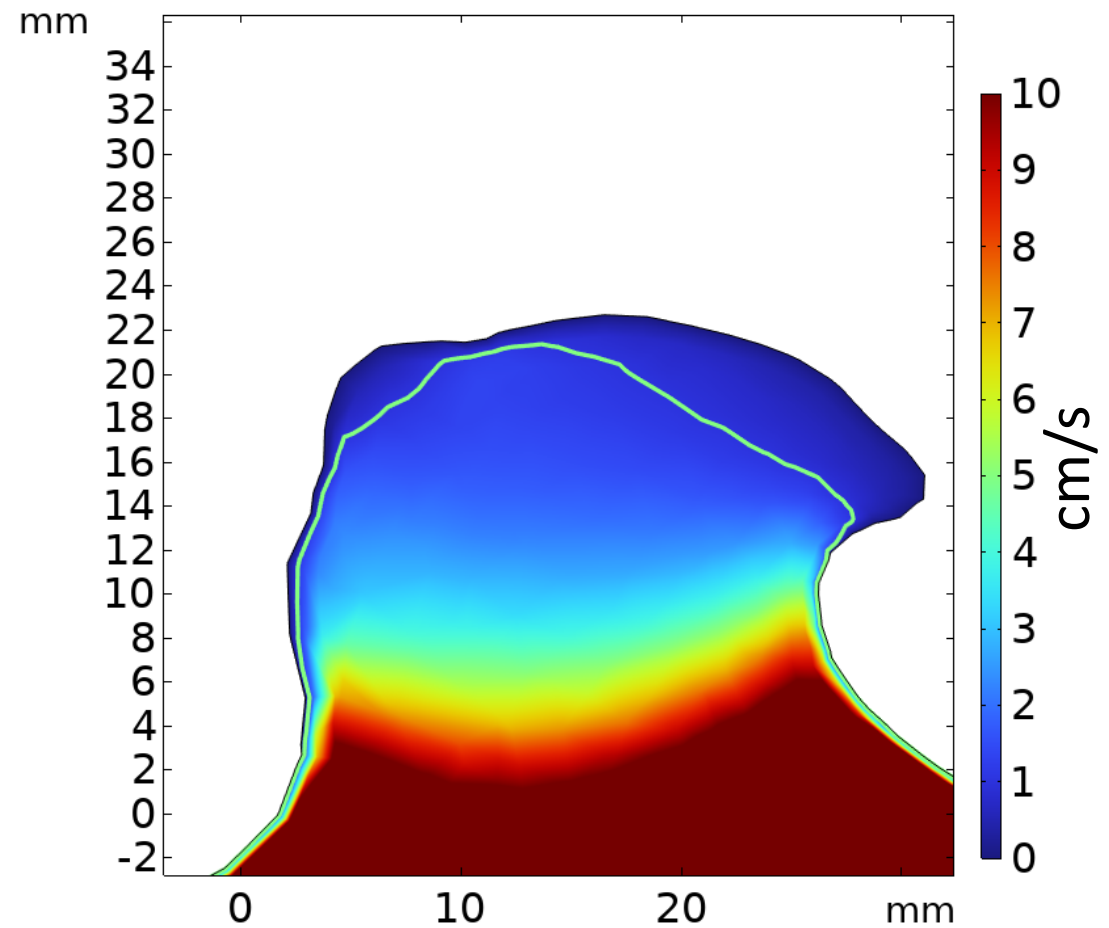
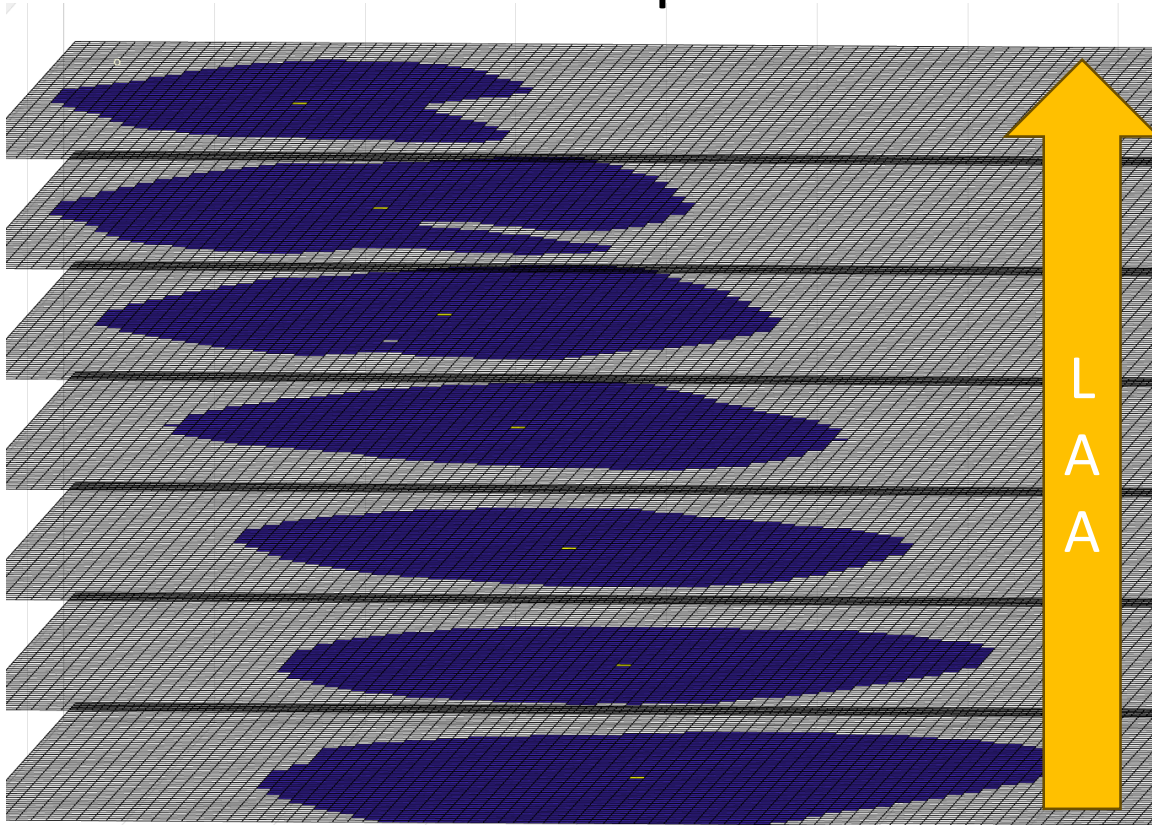
Pressure



Results Analysis

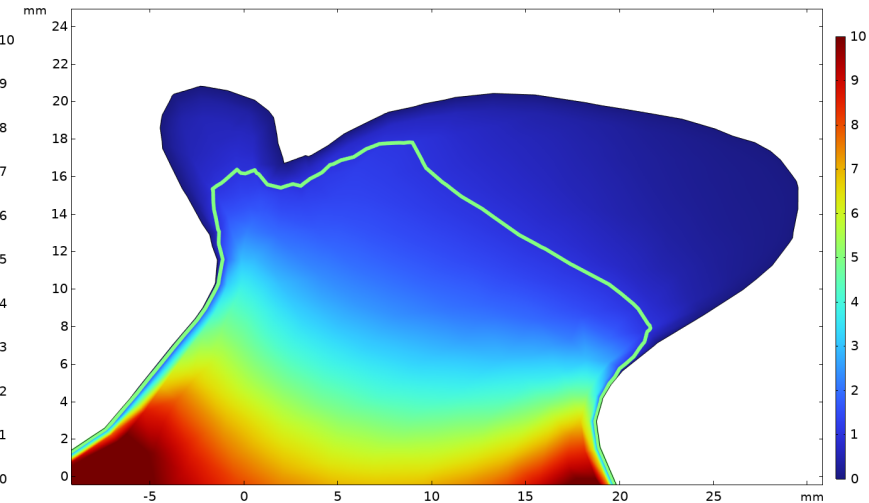
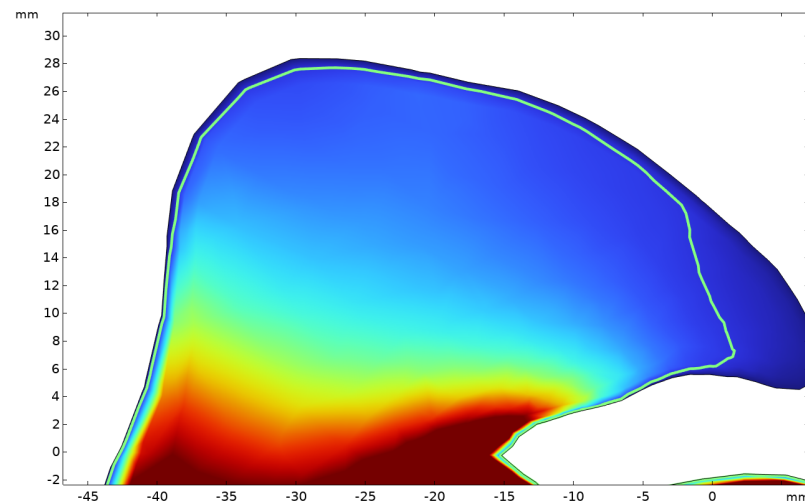
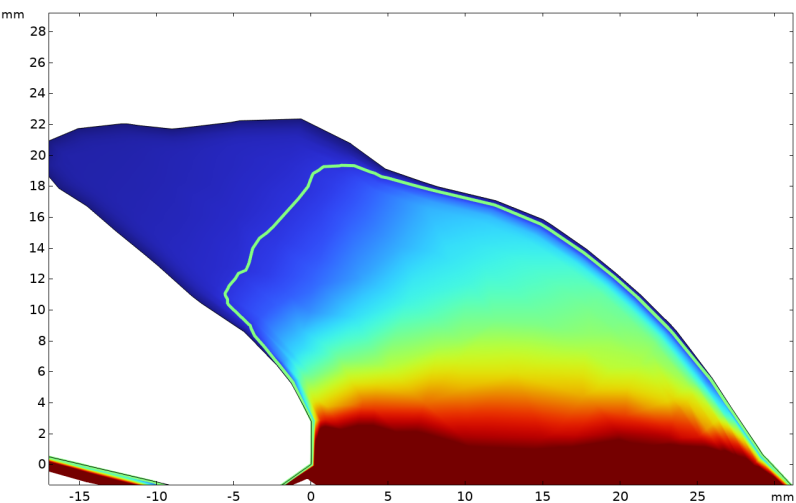
- Export to MATLAB – via Livelink

Define evaluation points in LAA



Patients cohort – feasibility study

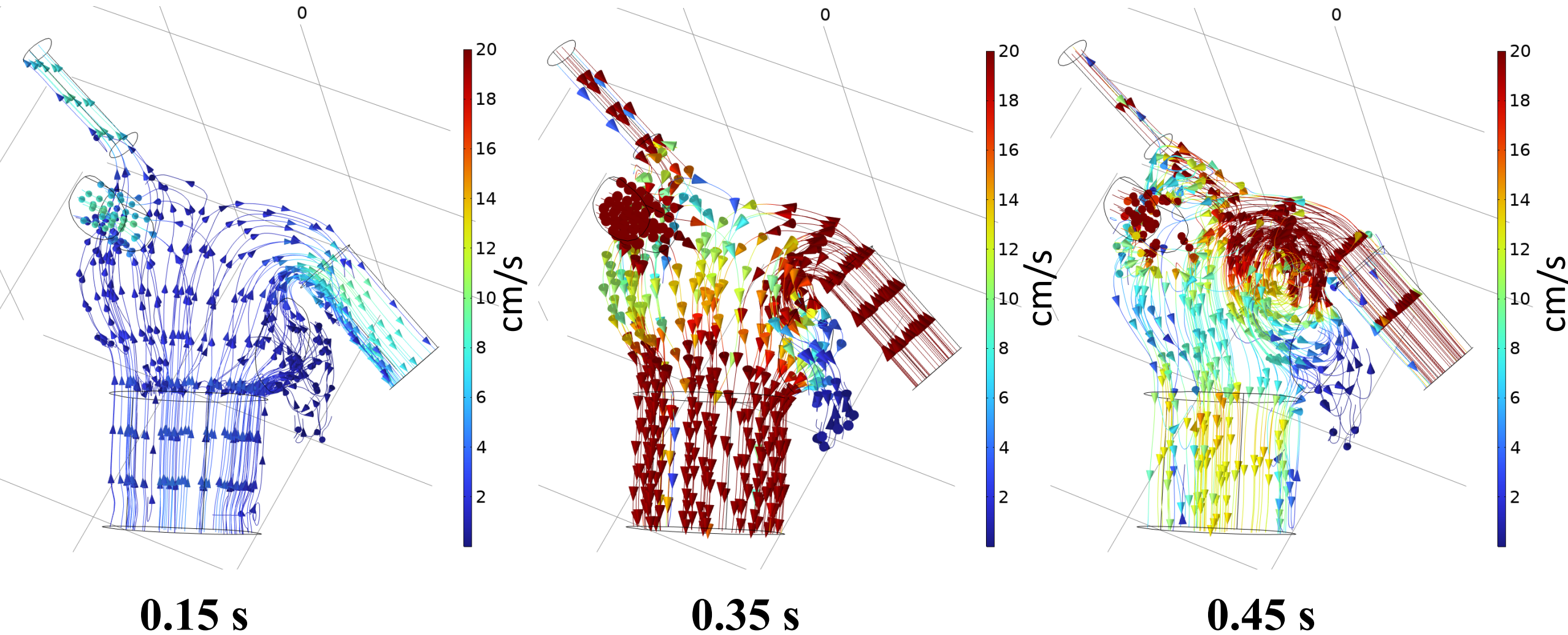
- Total 11 patients – with atrial fibrillation
 - 7 patients with **no** stroke: LAA length 31.7 ± 8.3 mm
 - 4 patients with **stroke** : LAA length 39.1 ± 16.2 mm
- Simulation of blood flow in left atrium

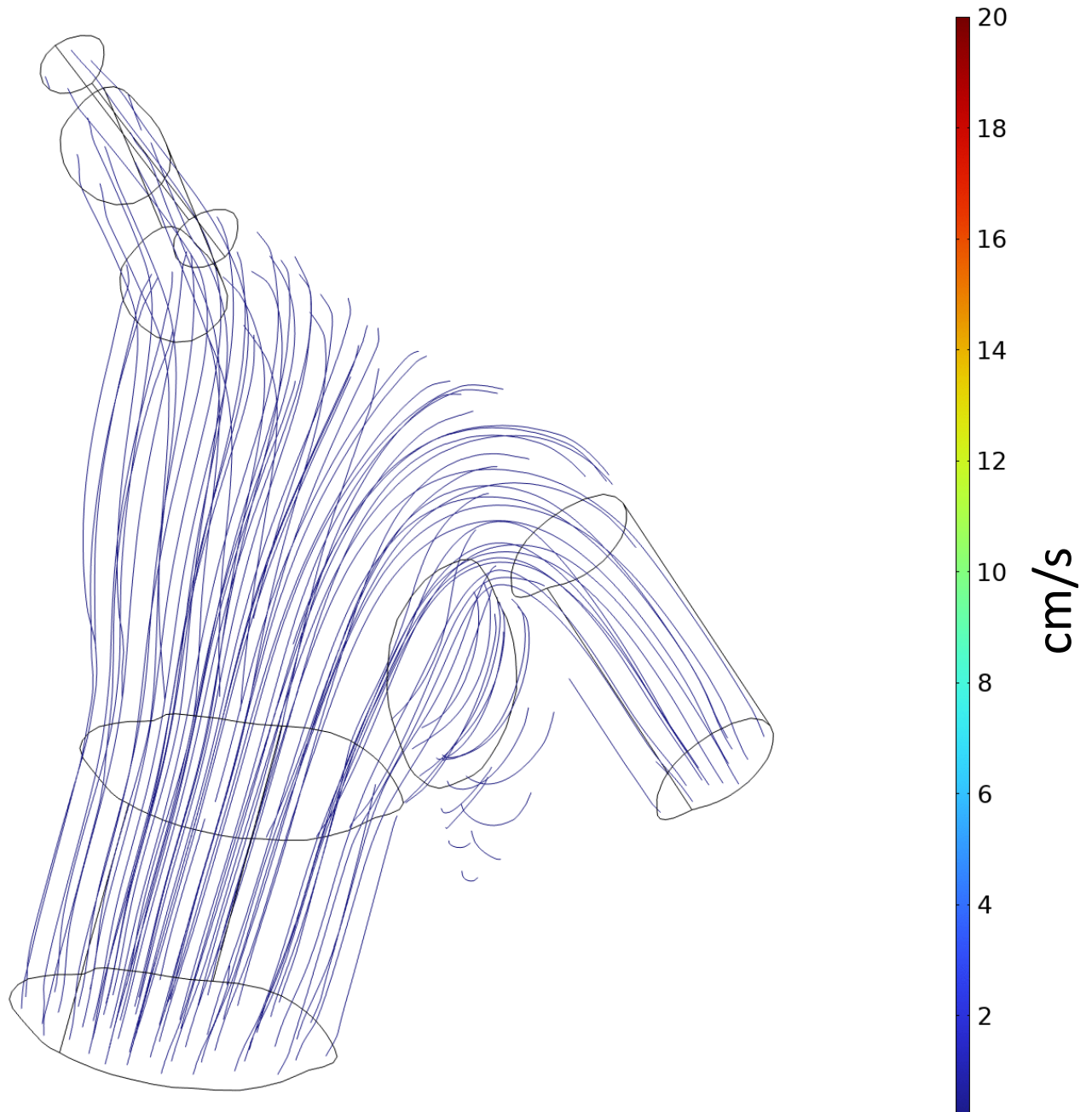


Results 2022/2023

Type	ID	Cardiac output (ml/cycle)	Cardiac output (l/min)	Appendage length (mm)
(N)	Patient 1	44.46	3.34	25
(N)	Patient 2	28.80	2.16	34.4
(C)	Patient 3	46.83	3.51	48
(N)	Patient 4	55.40	4.15	23.8
(N)	Patient 5	40.62	3.05	29.4
(C)	Patient 6	53.63	4.02	34.8
(C)	Patient 7	60.05	4.72	26.6

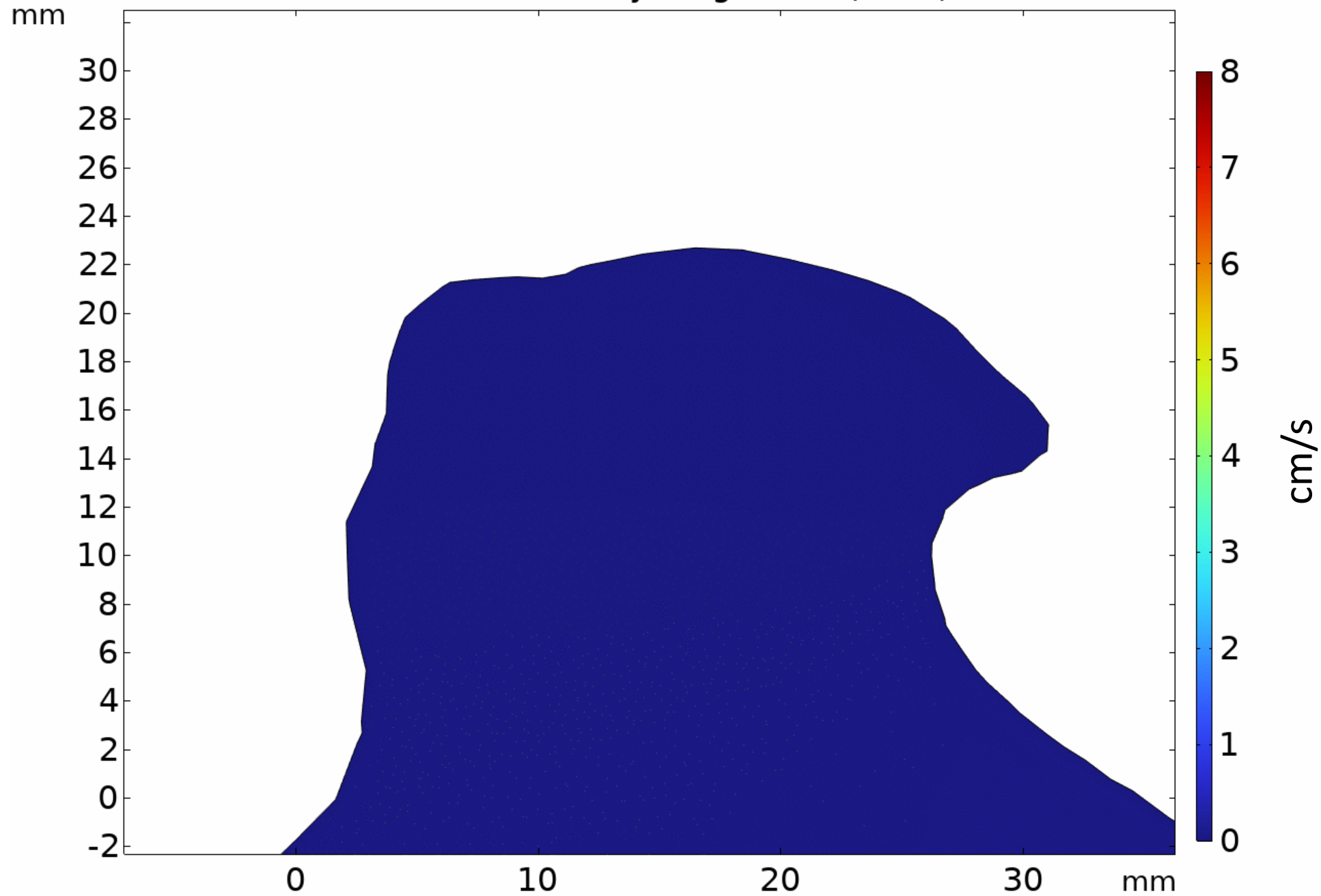
Results – blood flow velocity





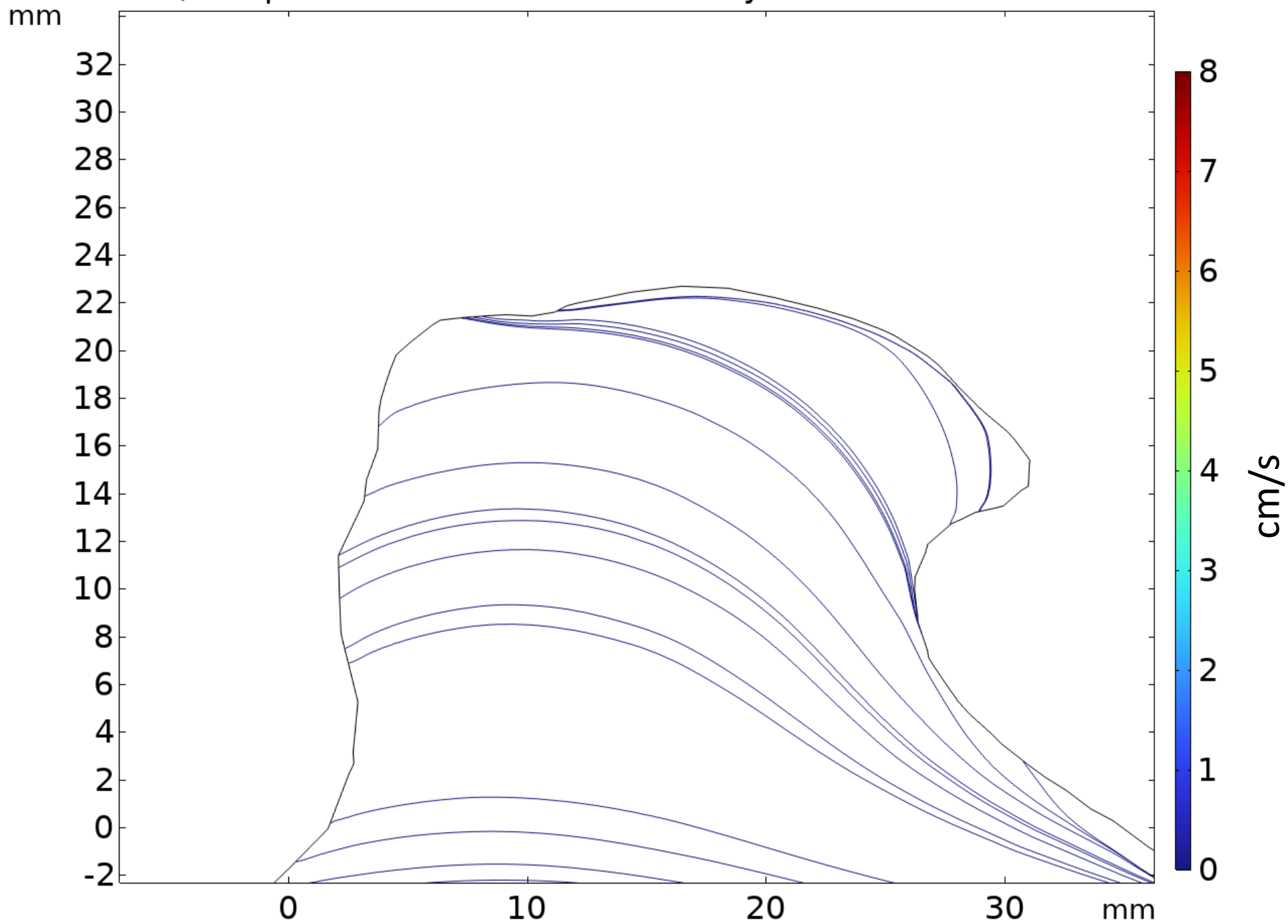
Time=0 s, ramp=1 Surface: Velocity magnitude (cm/s)

Contour: Velocity magnitude (cm/s)

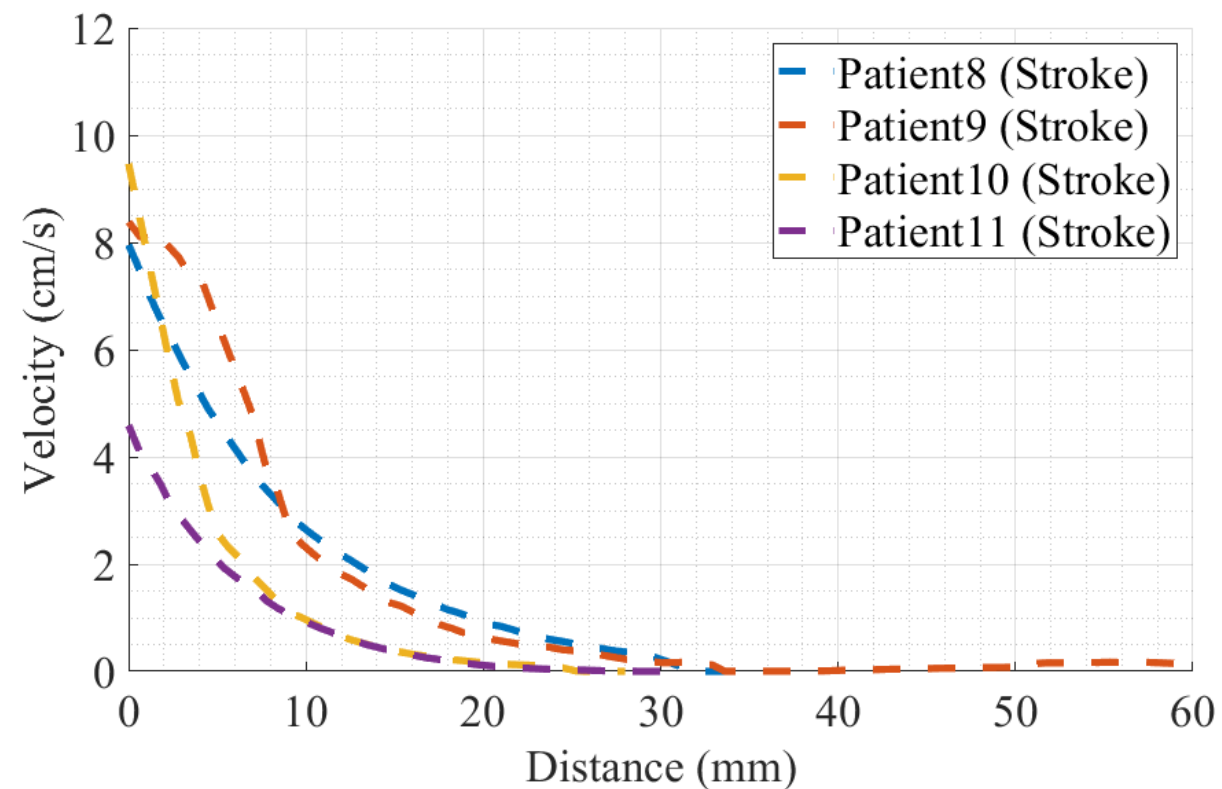
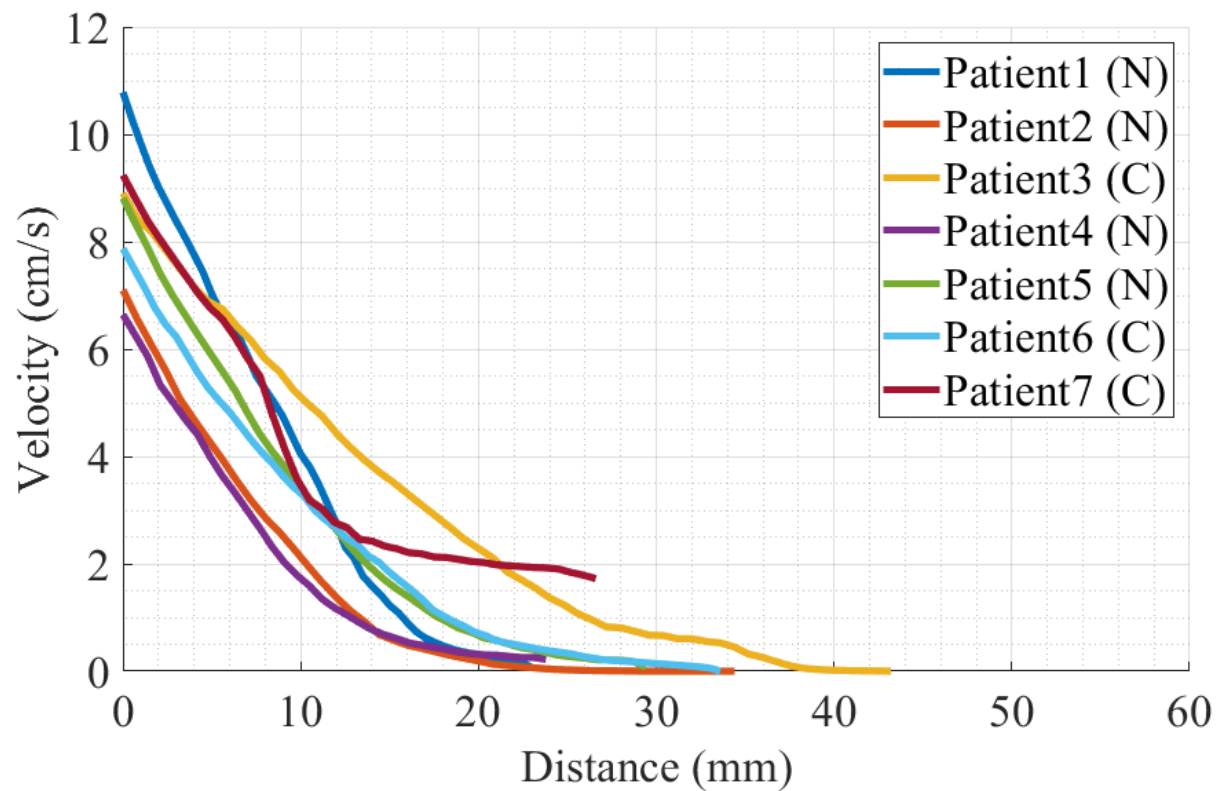


Time=0 s, ramp=1

Streamline: Velocity field



Time (s)	Maximum Blood velocity (cm/s)
0.15	9.59
0.35	79.14
0.45	48.24



Model verification



Conclusion

- Blood flow simulation in LA
- Patients after stroke have lower mean blood flow in LAA
- The critical blood flow velocity was defined at 1 cm/s
- Results indicate a direct correlation between LAA length and decreased flow rates below 1 cm/s, which in turn elevates the risk of thrombus formation
- This parameter may provide new possibilities to predict thrombus formation in patients with atrial fibrillation.

Thank you for your attention

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