Patient-Specific Modeling of Flow and Fluid-Structure Interaction in a Cohort of Patients with Multiple Cerebral Aneurysms

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BACKGROUND

- Aneurysm progression: due to **complex interplay** between biomechanics and clinical factors.
- Need to control **confounding risk factors** to uncover the underlying biomechanical principles.
- Growing and stable aneurysms in the same subject are affected equally by clinical risk factors: they act as **self-controls**.

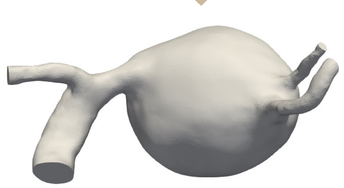
Stable and growing aneurysms in the same patient act as self-controls, allowing us to uncover biomechanical parameters indicating aneurysm progression

COMPUTATIONAL FLUID-STRUCTURE INTERACTION MODEL

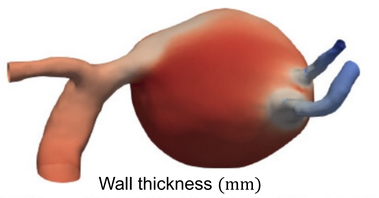
- **Nonuniform vessel wall thickness** due to arterial branching and aneurysmal disease.
- Accounts for **arterial wall prestress**, as would be expected for *in vivo* state of the arterial wall.
- Accounts for mechanical **support from surrounding tissue**.

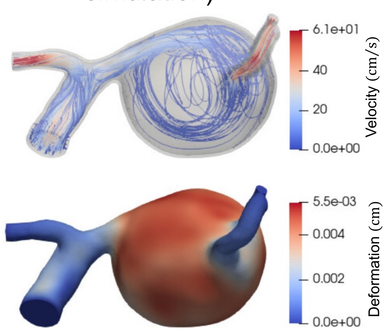
MODELING WORKFLOW

3D lumen geometries extracted from CT images (from IUSM) + **longitudinal imaging**



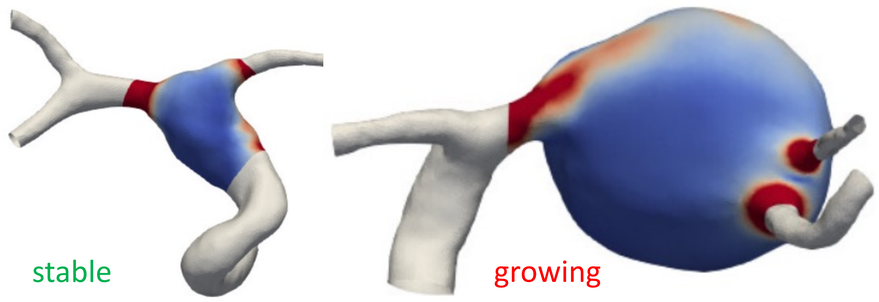
arterial wall geometry accounting for tapering and effect of wall shear (from rigid-wall simulation)





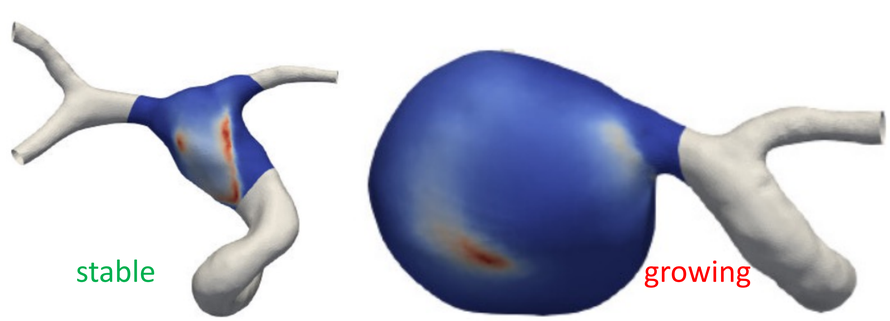
Fluid-structure interaction simulations using SimVascular (svFSI) simulate blood flow coupled with arterial wall deformation

CASE STUDY: SUBJECT WITH ANEURYSMS OF INTERNAL CAROTID AND MIDDLE CEREBRAL ARTERY

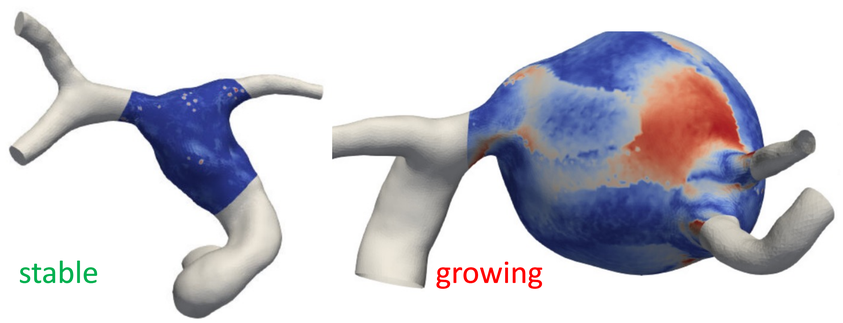


Normalized time-averaged wall shear stress (TAWSS) $(\mathrm{dyne}/\mathrm{cm}^2)^*$

*Normalized with respect to time-averaged wall shear stress on parent vessel.



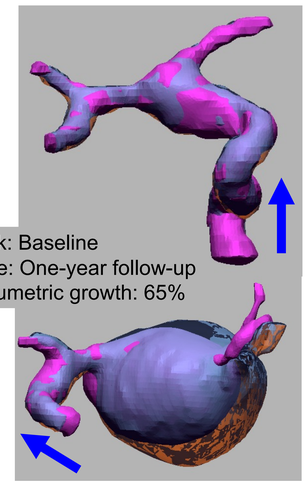
Oscillatory shear index (OSI)



Orientation of maximum principal stress at peak systole⁺

Tensile/stress load — Normal stress/load

⁺ With respect to local surface normal.



KEY TAKEAWAYS

- Quantified wall shear stress (WSS), arterial wall stresses & oscillatory shear index (OSI).
- Larger ($\approx 40\%$) area under low WSS in growing aneurysm as compared to stable one ($\approx 16\%$).
- Areas of abnormally high wall shear & tensile stress or low shear & normal stress on growing aneurysm may favor remodeling.

REFERENCES

1. Rayz & Cohen-Gadol, Hemodynamics of Cerebral Aneurysms: Connecting Medical Imaging and Biomechanical Analysis, *Annu. Rev. Biomed Eng.,* 2020.
2. Lan *et al.*, A re-engineered software interface and workflow for the open-source SimVascular cardiovascular modeling package, *J. Biomed. Eng.*, 2018.
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SPECIFIC AIMS OF THE PROPOSED RESEARCH

1. Develop a computational methodology that accurately simulates the **coupled effect of wall compliance and flow dynamics** related to vessel remodeling and aneurysm growth.
2. Conduct image-based fluid-structure interaction simulations for a **cohort of patients with multiple aneurysms** to determine the difference in biomechanical risk factors between stable and growing aneurysms.