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: a **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**.

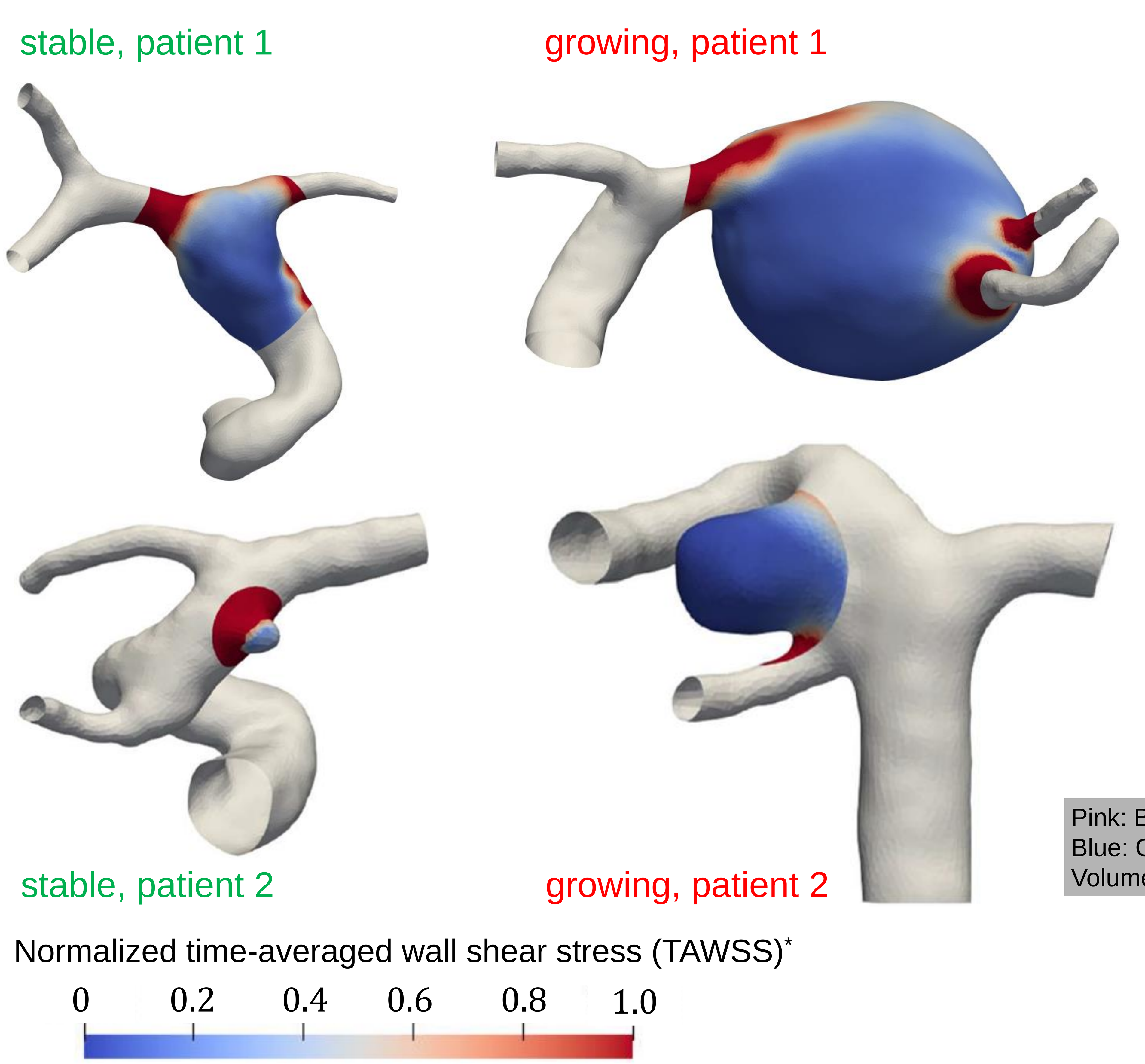
Stable and growing aneurysms in the same patient act as self-controls, allowing us to uncover biomechanical parameters indicating aneurysm progression

COMPUTATIONAL FLUID–STRUCTURE INTERACTION MODEL

- Has **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.

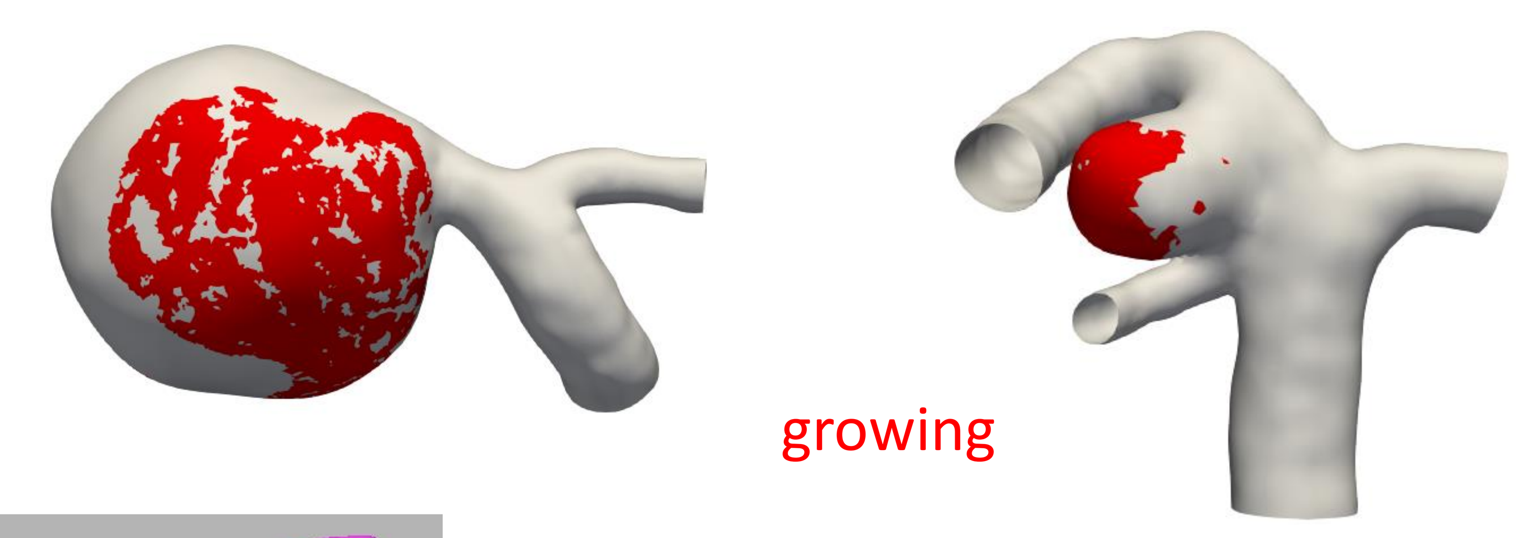
COMPARATIVE ANALYSIS OF TWO PAIRS OF STABLE AND GROWING ANEURYSMS IN SAME SUBJECT

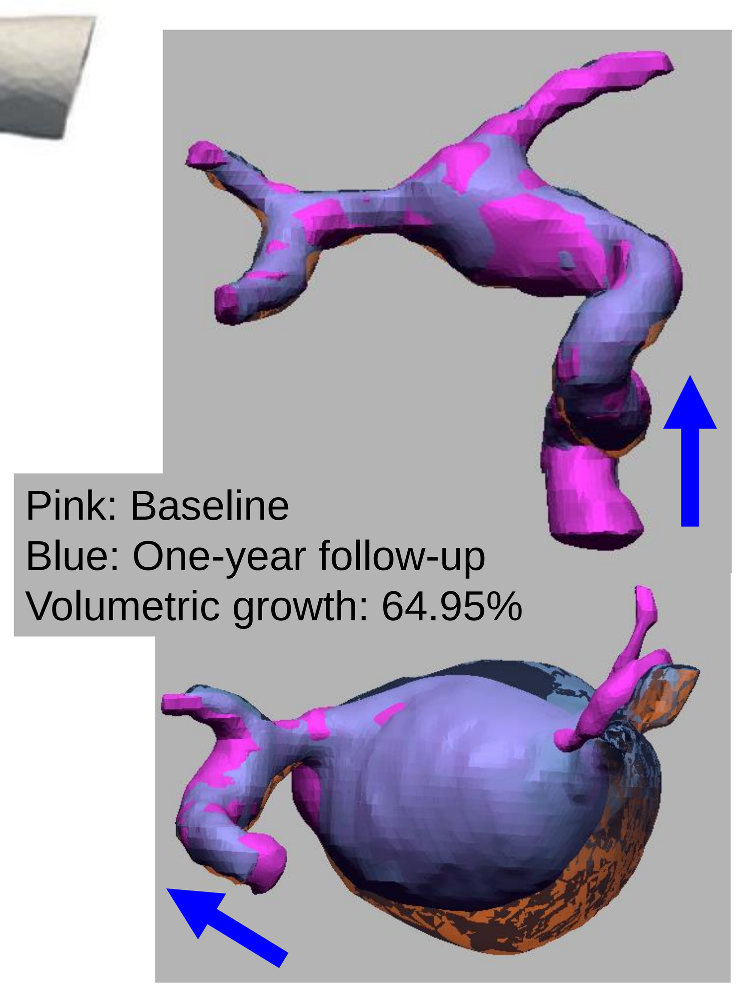
- Growing aneurysms have lower time-averaged wall shear stress (TAWSS). But that's insufficient to determine their growth risk.



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

- **Oscillating arterial stress index** (**OStI**) is proposed as a biomechanical marker for aneurysm growth.
- Growing aneurysms exhibit **larger combined regions** (shown in red) of low TAWSS and low OStI:[4]

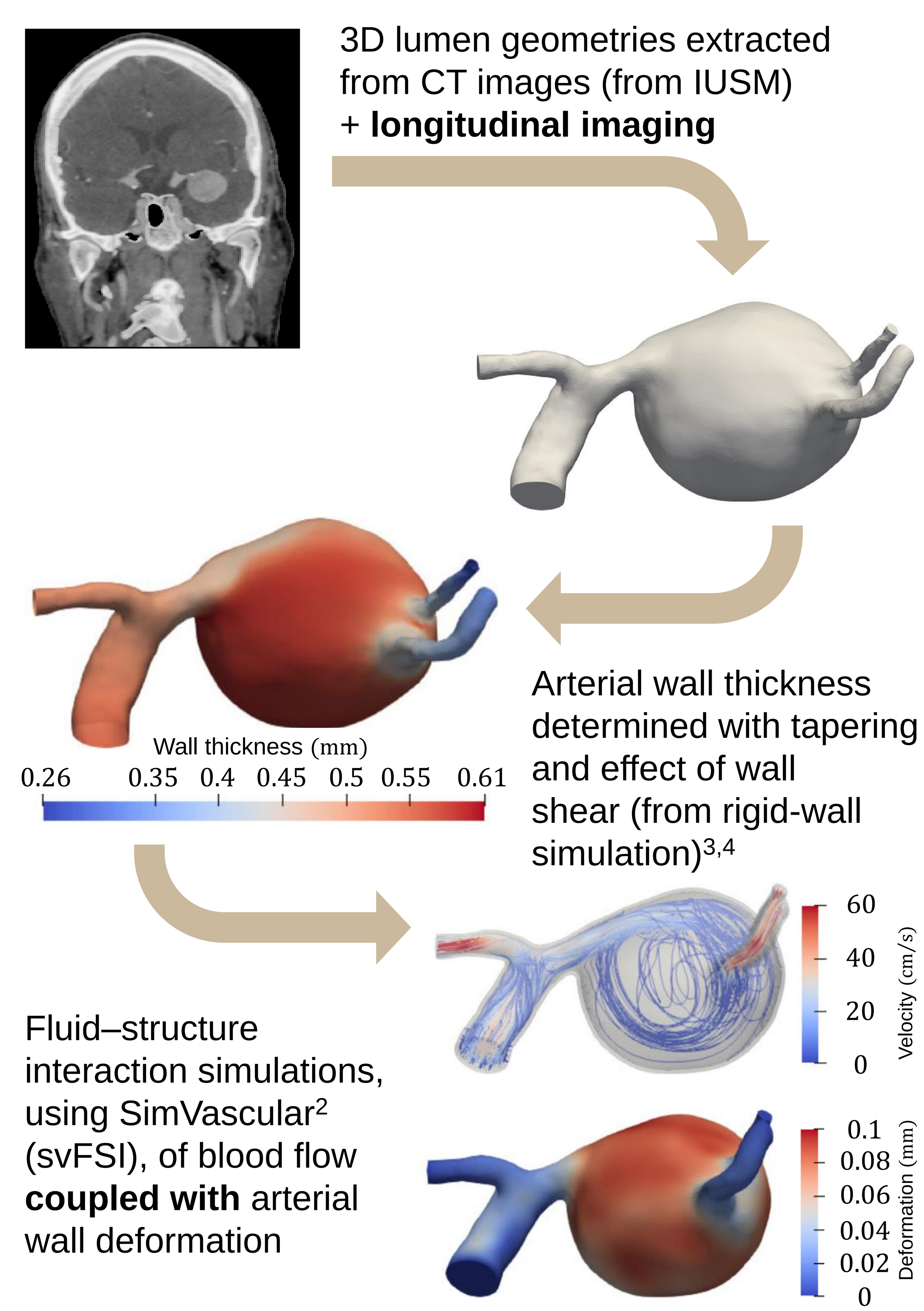




KEY TAKEAWAY

- Uncovered relevance of the combination of wall shear and oscillating arterial stress.
- Low wall shear & fluctuating stress (specifically, $\mathrm{TAWSS}^* < 0.1$ and $\mathrm{OStI} < \cos 15°$) $\Rightarrow$ Replacement of degraded collagen fibers with remodeled weaker fibres.

MODELING WORKFLOW



SELECTED 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. Biomech. Eng.*, 2018.
3. Shidhore *et al.*, Estimating external tissue support parameters with fluid-structure interaction models from 4D ultrasound of murine thoracic aortae, *Engineering with Computers*, submitted, 2022.
4. Shidhore *et al.*, Comparative assessment of biomechanical parameters in subjects with multiple cerebral aneurysms using fluid-structure interaction simulations*, J. Biomech. Eng.*, submitted, 2022.

OUTCOMES FROM THIS STUDY

1. Found unique cases of patients with **a growing and a stable aneurysms** that act as self-controls for clinical risk factors.
2. Developed methodology to simulate **coupled effect of wall compliance and flow** on biomechanical parameters.
3. Discovered that **combined regions under low shear and low oscillating wall stress** relate to aneurysmal growth.

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