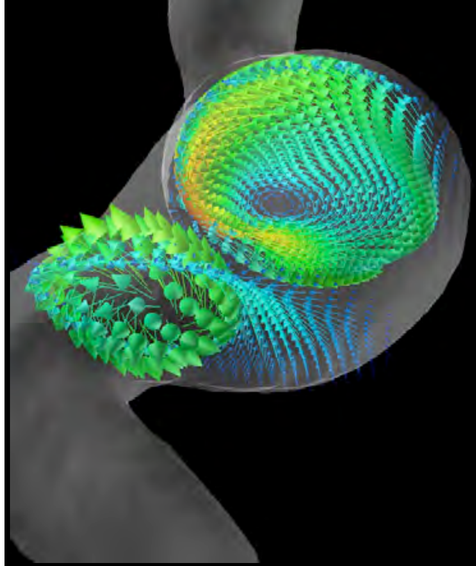
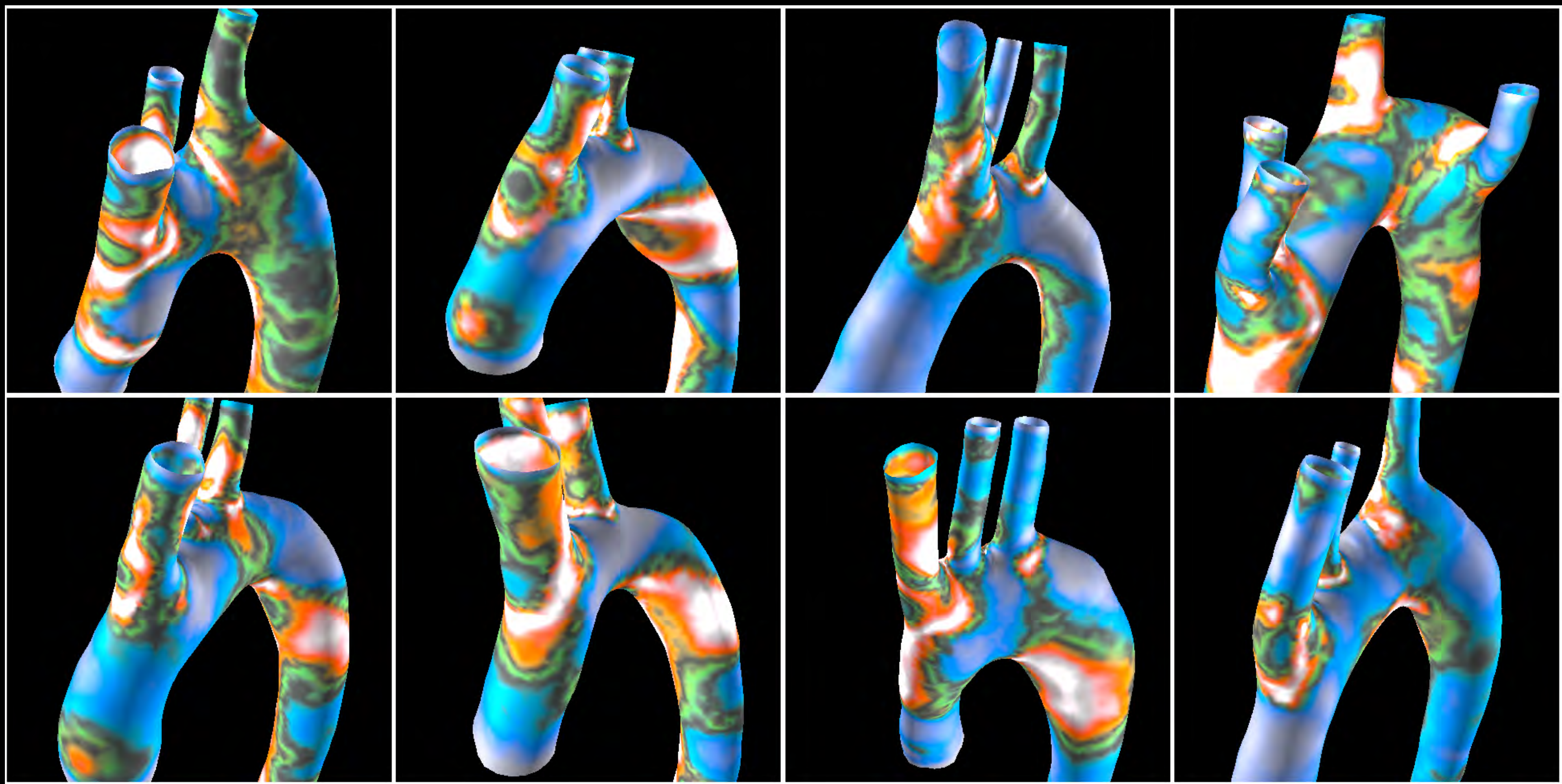


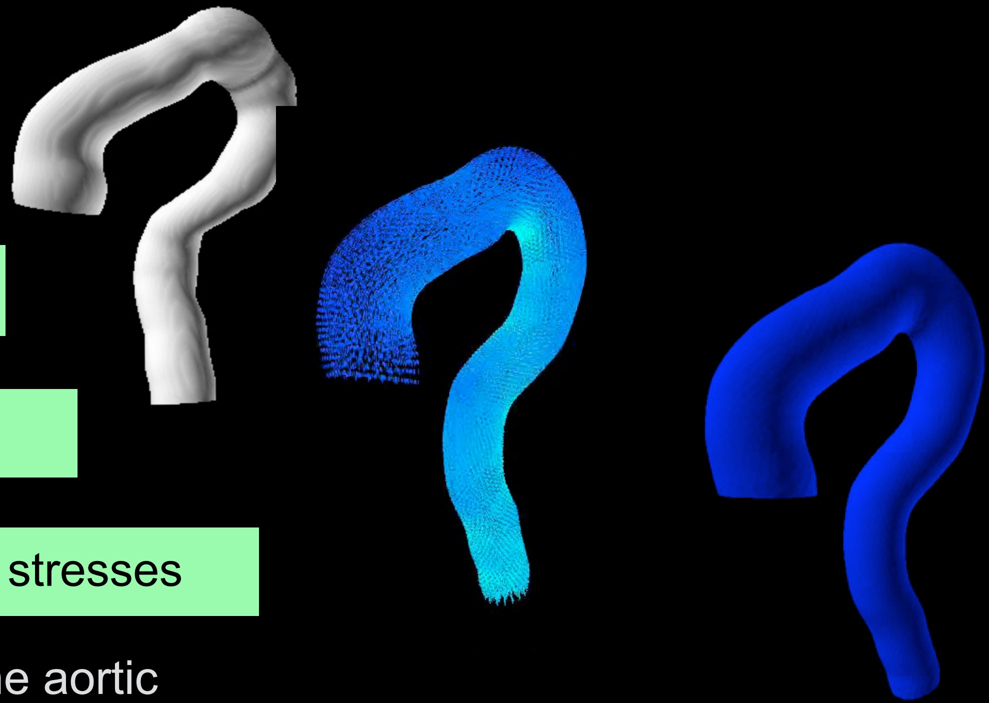
JRSMIT2015, 4-6 Mar 2015, Moscow

Vortical flows in the aorta and their relations to geometrical characteristics

H. Suito (Okayama University)
T. Ueda (St. Luke's Int. Hospital)



Objectives



Difference in original aorta geometries

Difference in flow fields

Difference in wall shear stresses

There are so many parameters affecting the aortic aneurysms, such as tissue remodeling, mechanical properties of the stent graft, etc. We are seeking the most appropriate parameterization of aorta shapes strongly related to WSS distributions.

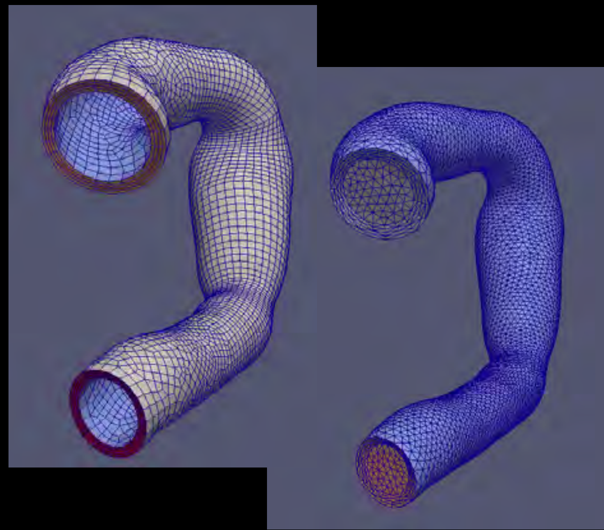
- What kind of geometrical characteristics brings about difference of wall shear stress?

- Optimize follow-up strategies after cardiovascular treatments depending on patient-specific conditions.
- Predict where the aneurysm would be developed, depending on patient-specific morphology characteristics.

Computational Method for Fluid-Structure Interaction

T. Tezduyar and K. Takizawa

- Deforming-Spatial-Domain/Stabilized-Space–Time Method (DSD/SST)
- Variational Multiscale （VMS) method
- Sequentially-Coupled Arterial FSI (SCAFSI) Technique



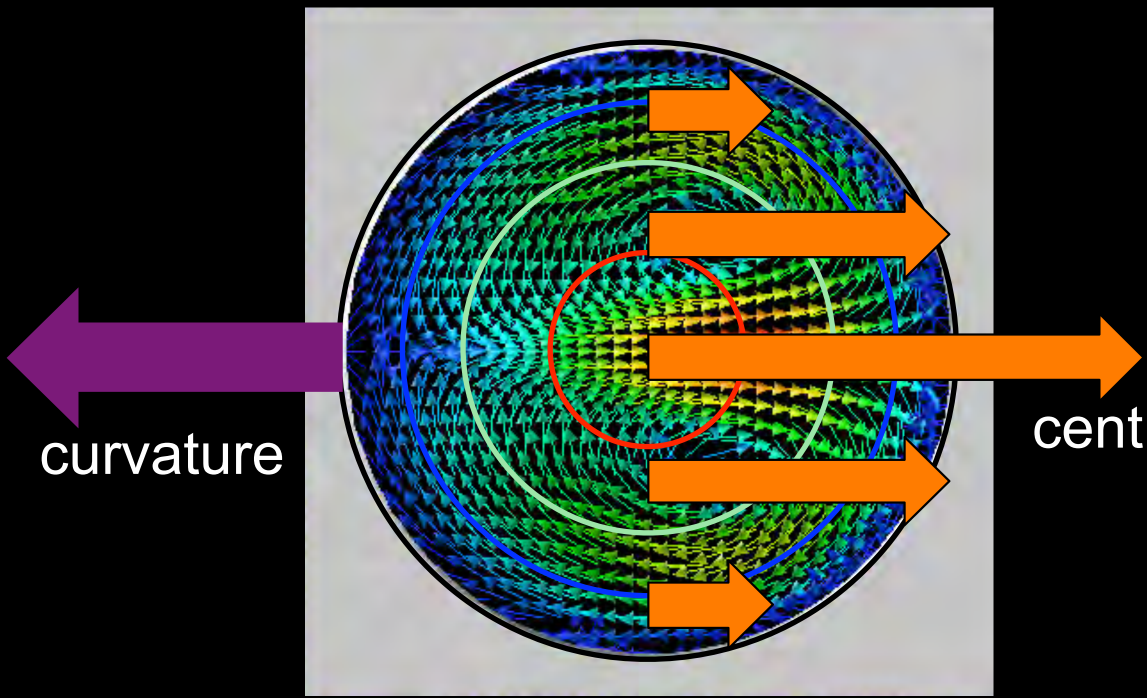
[1] T.E. Tezduyar, "Stabilized finite element formulations for incompressible flow computations", Advances in Applied Mechanics, Vol. 28, pp. 1–44 (1992).

[2] K. Takizawa and T.E. Tezduyar, "Multiscale space–time fluid–structure interaction techniques", Computational Mechanics, Vol. 248, No. 3, pp. 247–267 (2011).

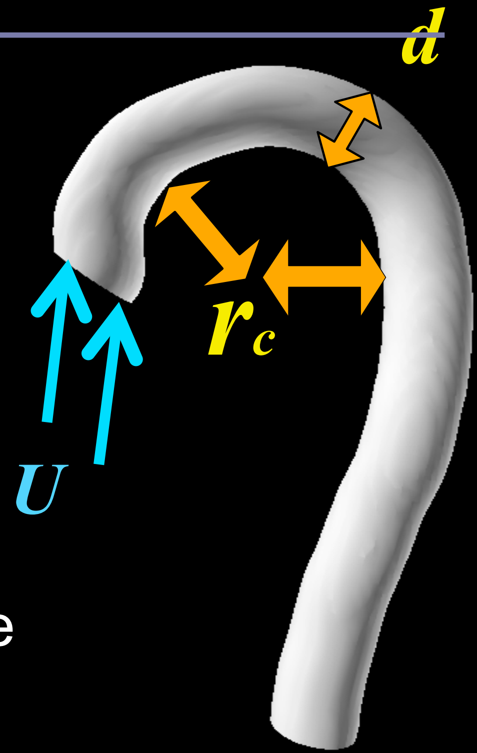
[3] T.E. Tezduyar, K. Takizawa, C. Moorman, S. Wright and J. Christopher, "Multiscale Sequentially-Coupled Arterial FSI Technique", *Computational Mechanics*, Vol. 46 17–29 (2010).

Dean’s vortices

Curvature plays an important role for flows in tubes.



Dean’s twin vortices

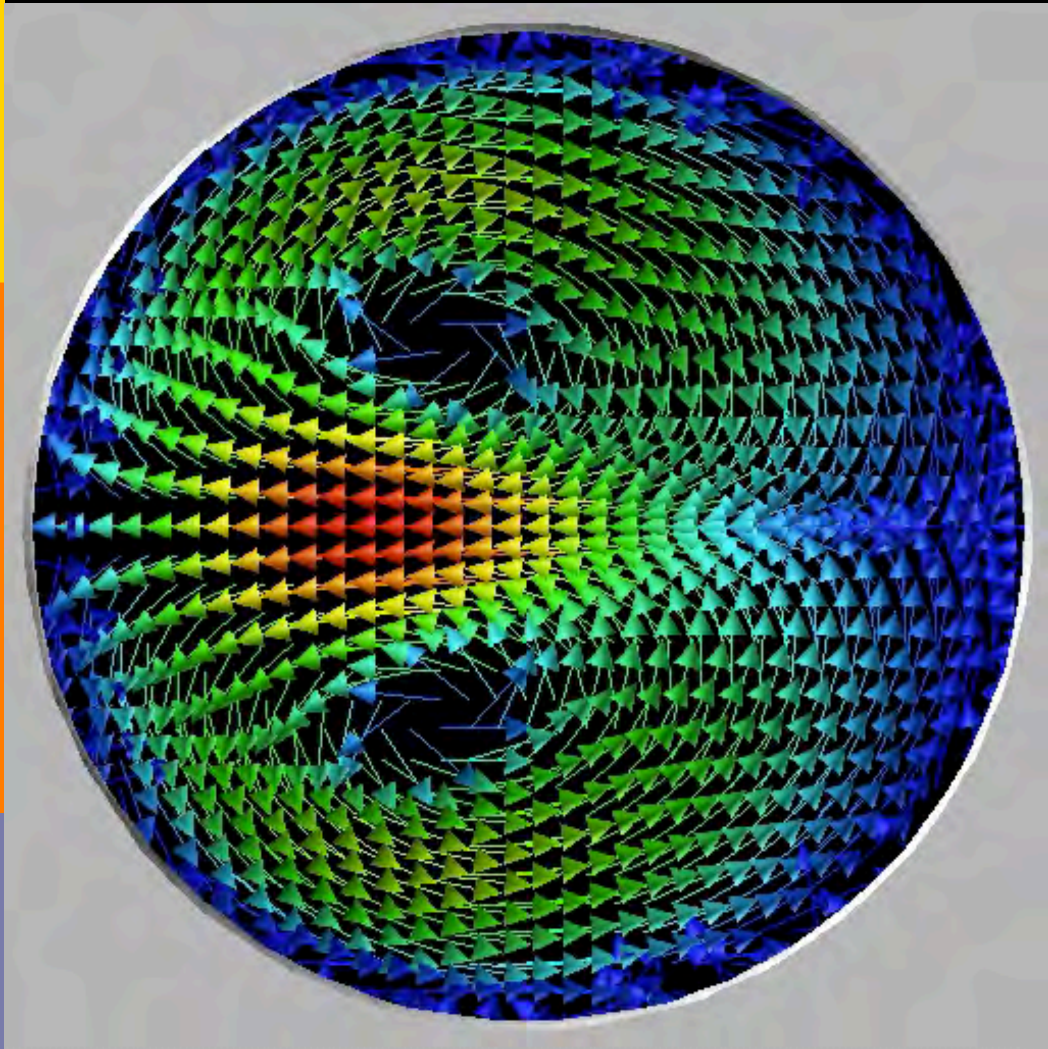


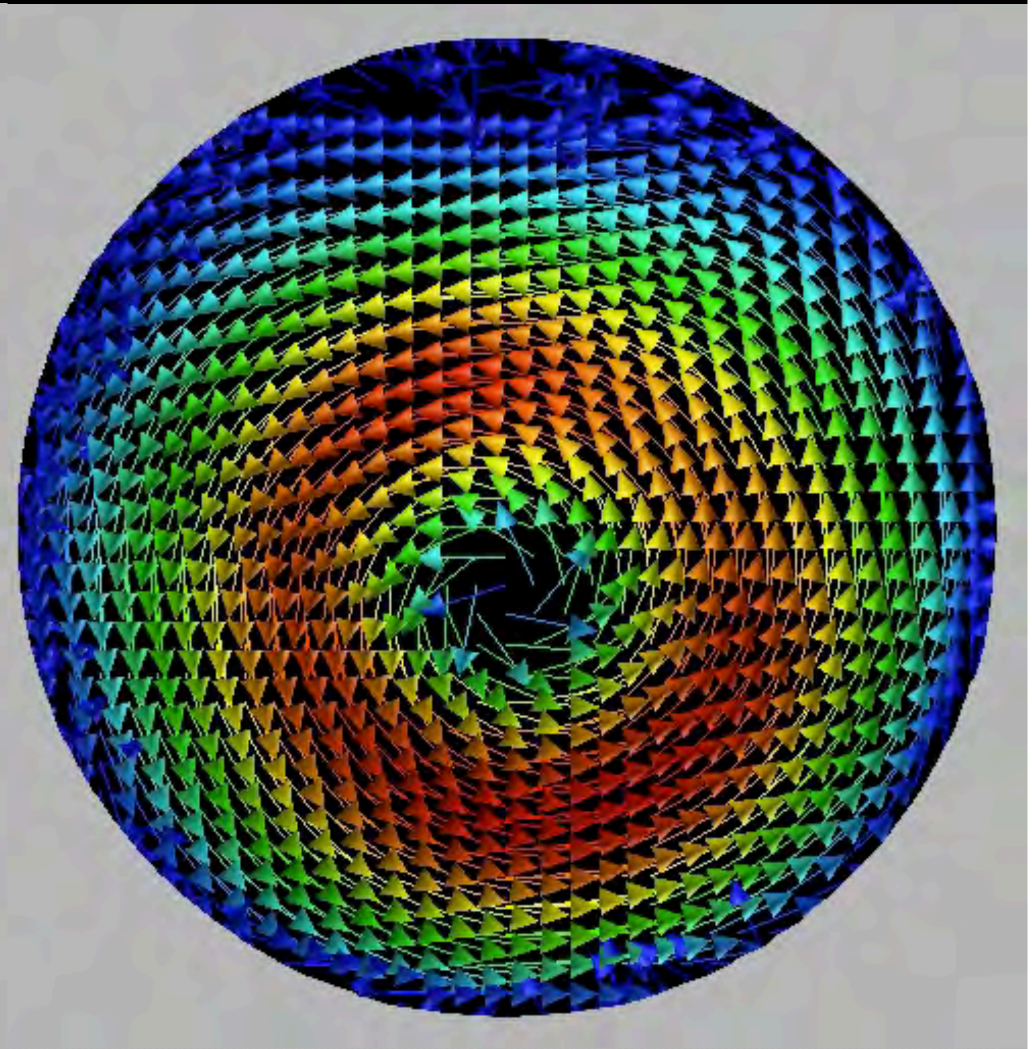
Dean’s number

$$De = 4\sqrt{\frac{d}{r_c}}$$

(1) In the straight circular tube, Hagen-Poiseuille flow profile is achieved.
(2) If the tube has a curvature, the centrifugal force acts in the opposite direction of the curvature.
(3) The centrifugal force is proportional to the velocity in the axis direction.
(4) Consequently, a set of opposite-sign vortices is generated as a secondary flow.

Secondary flows



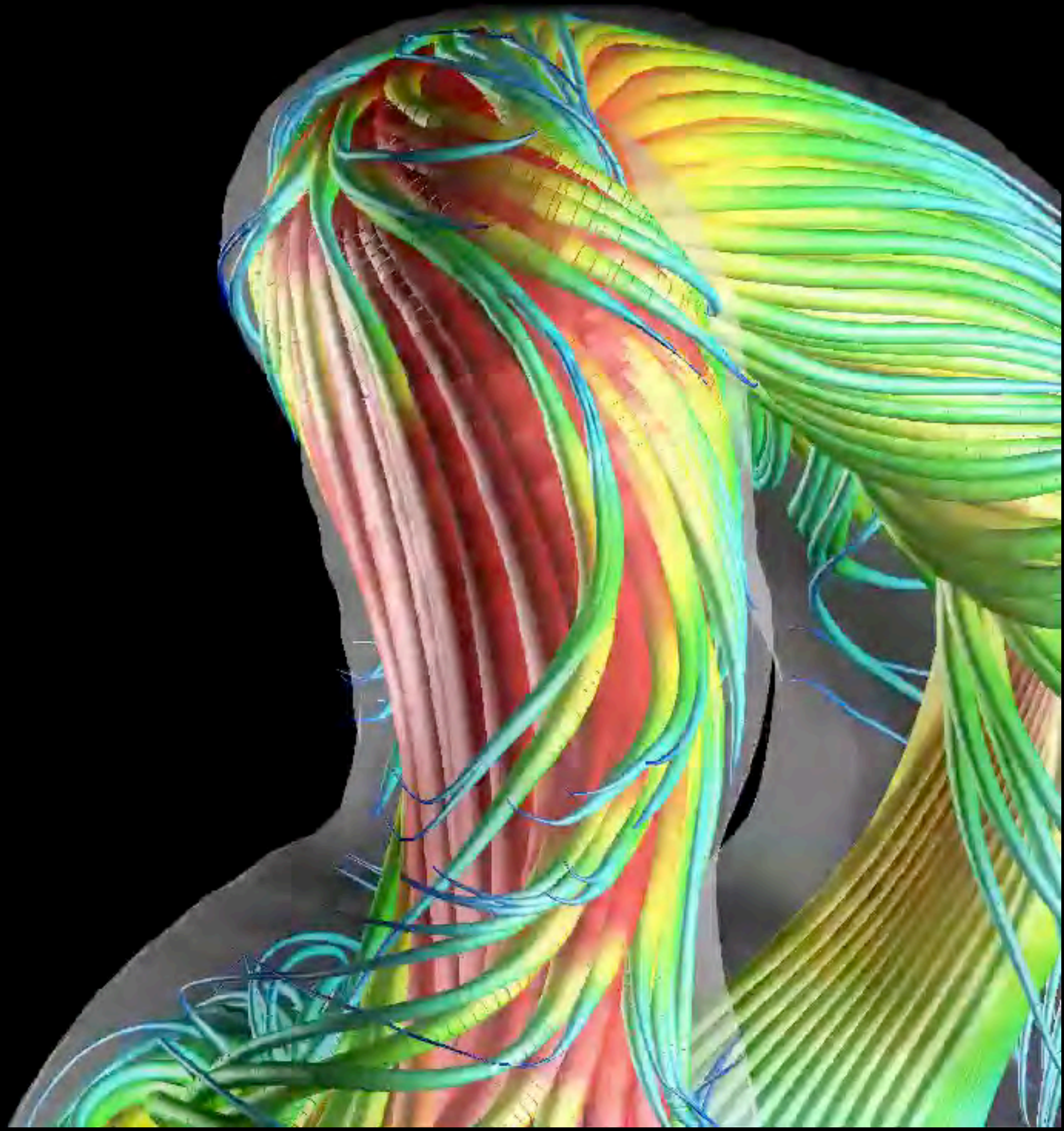


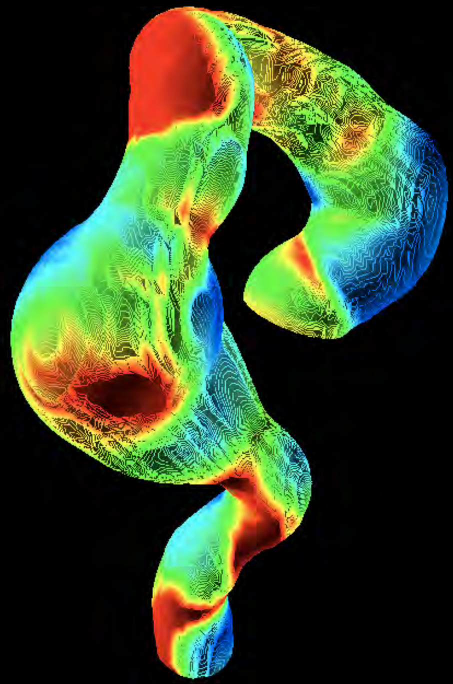
Torsion = 0.0

Torsion = 5.0

In the right hand side movie, merging and growing history of the one vortex can be seen.

Instantaneous streamlines





Distribution of time-averaged wall shear stress

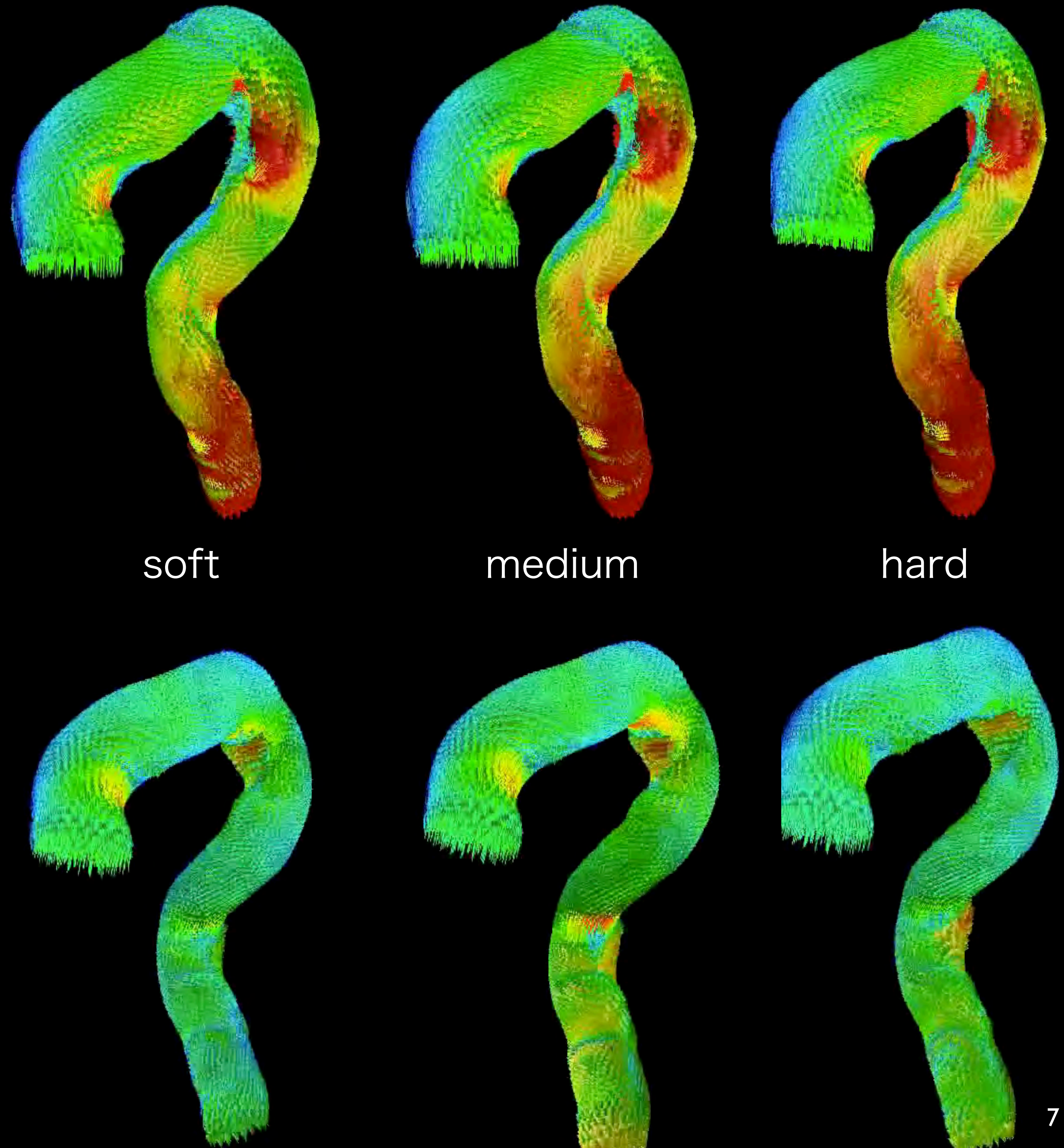
$$\sigma_i = \left\{ -p\delta_{ij} + \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) \right\} n_j$$

$$\boldsymbol{\sigma}_\tau = \boldsymbol{\sigma} - (\boldsymbol{\sigma} \cdot \boldsymbol{n})\, \boldsymbol{n}$$

Velocity vectors
considering FSI

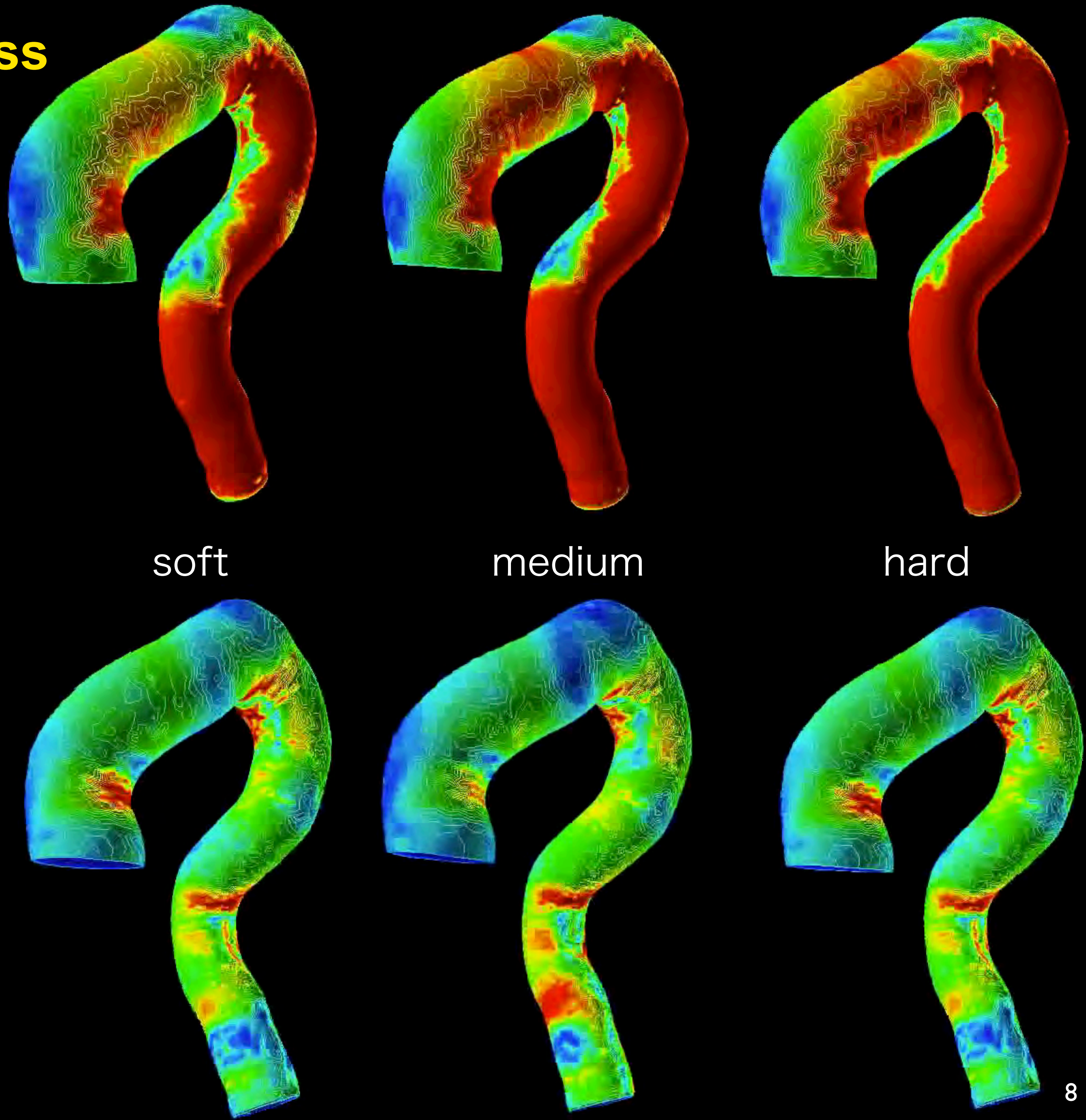
without torsion

with torsion



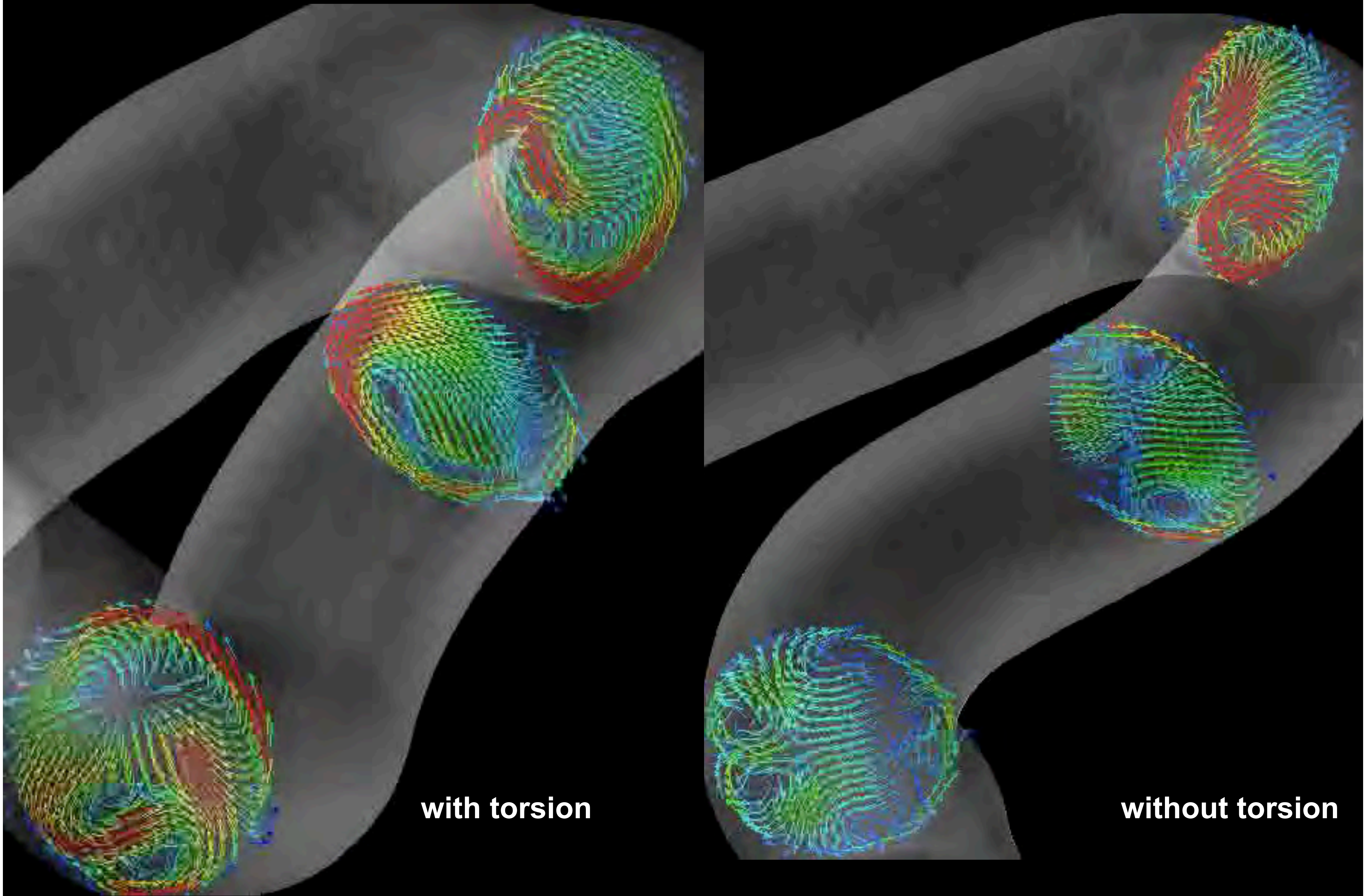
Wall Shear Stress

without torsion



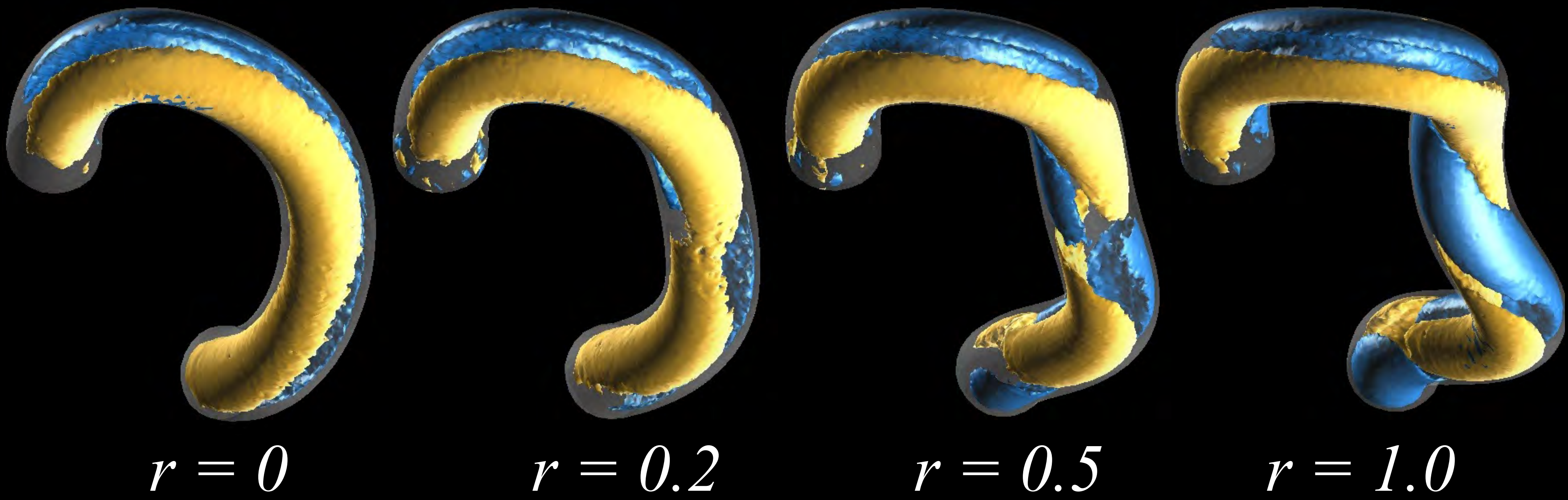
with torsion

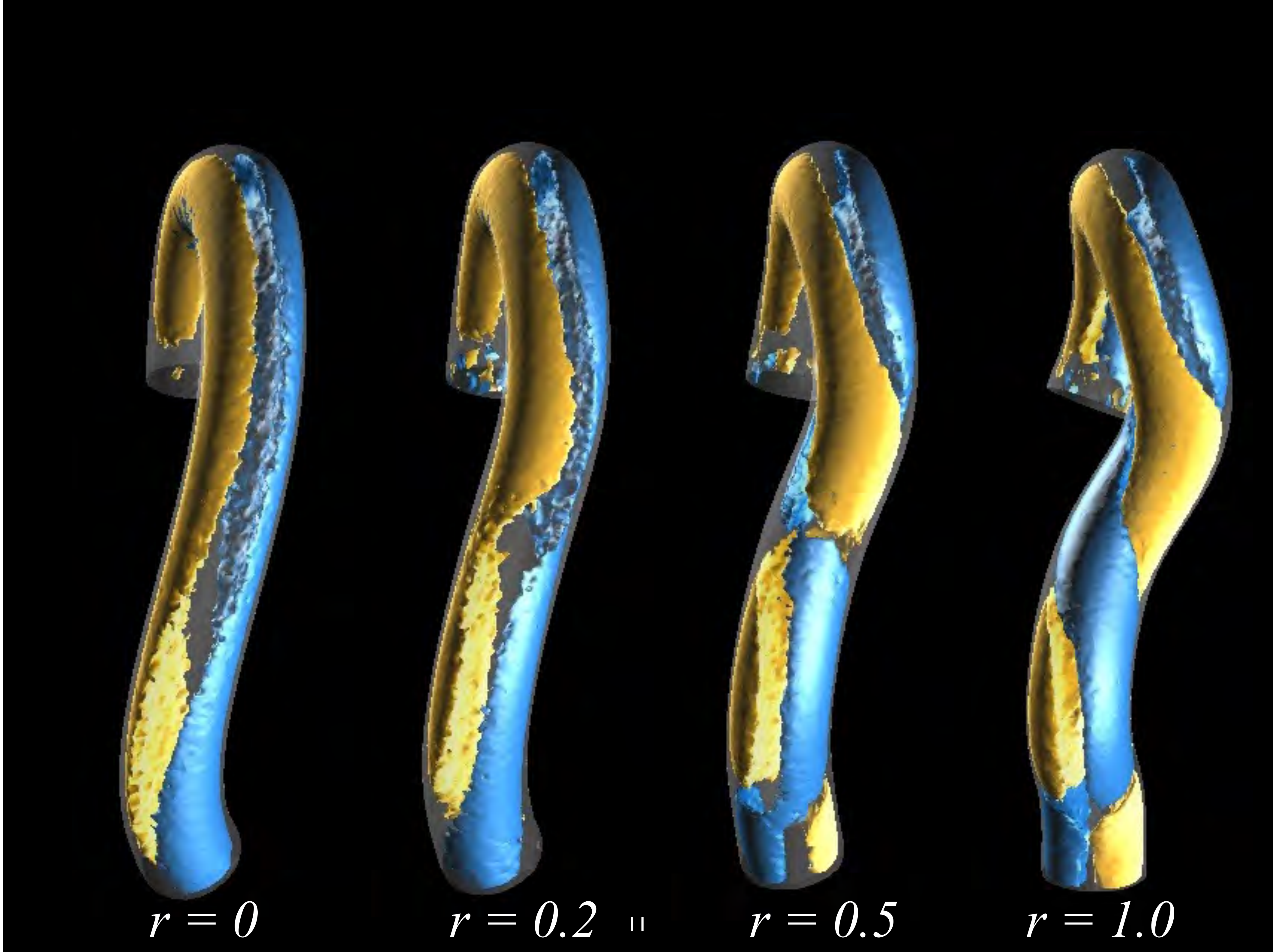
Secondary flows

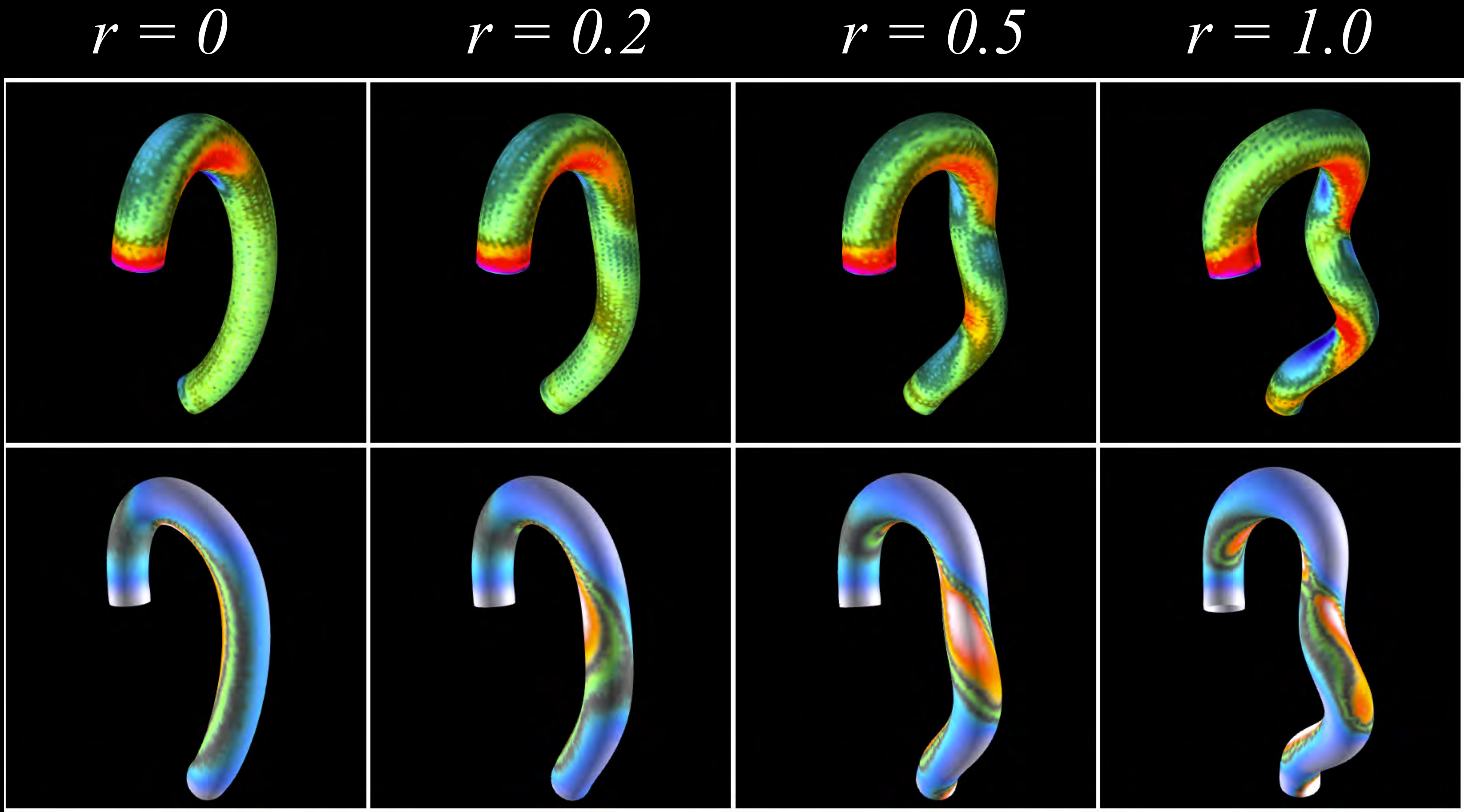


Helicity : $\boldsymbol{u} \cdot (\nabla \times \boldsymbol{u})$

- Helicity shows spiral-flow area.
- In the cases the deviations from the reference curve are large, high helicity areas show spiral shapes.




r = 0
r = 0.2
r = 0.5
r = 1.0

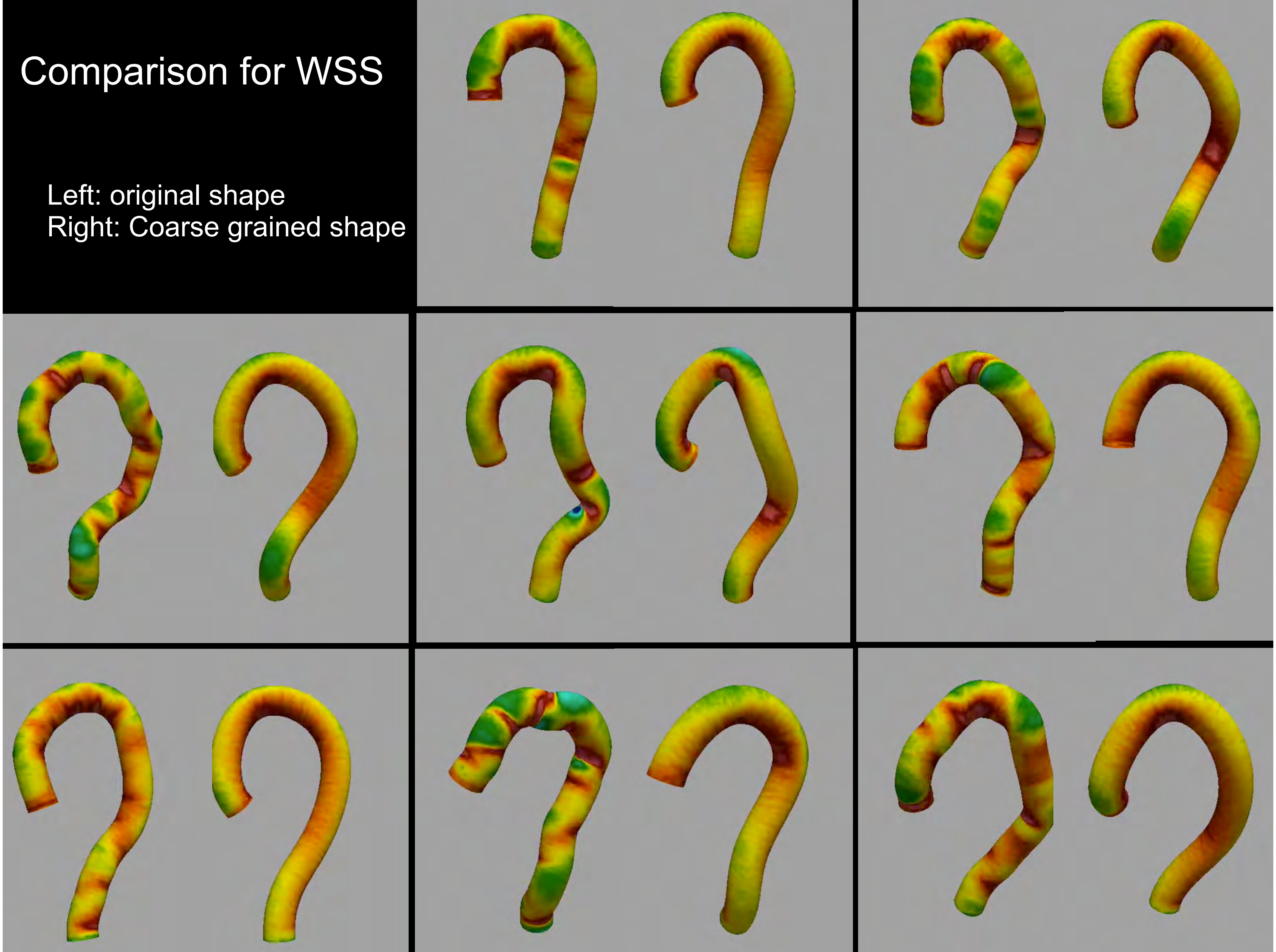


- High wall shear stress and high OSI area goes around to the outer side.

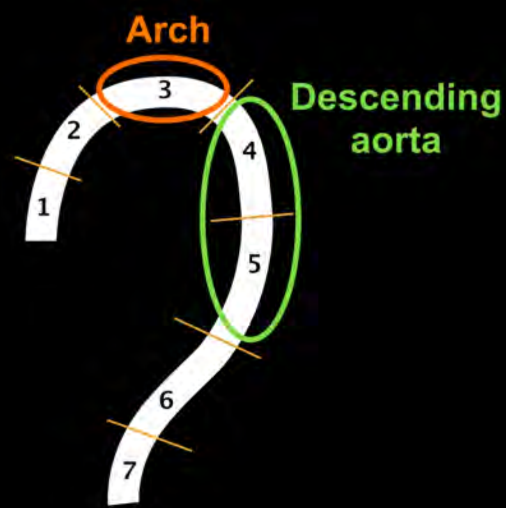
$$OSI = 0.5\left(1 - \frac{\left|\int_0^T WSS dt\right|}{\int_0^T |WSS|\, dt}\right)$$

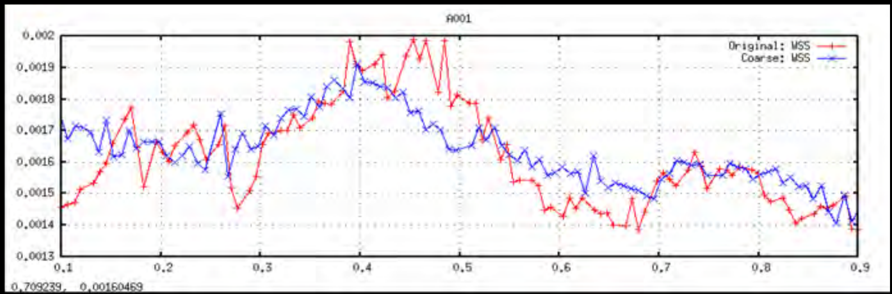
Comparison for WSS

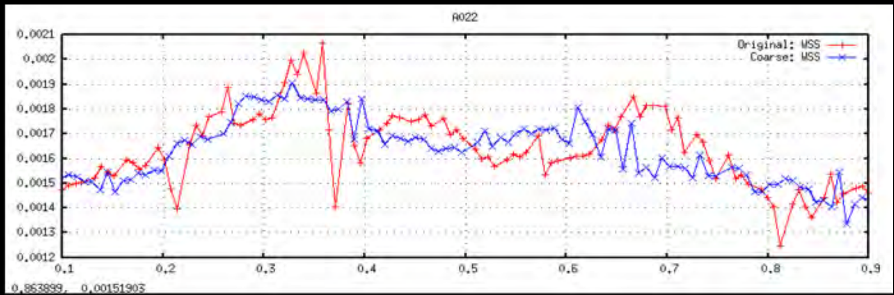
Left: original shape
Right: Coarse grained shape

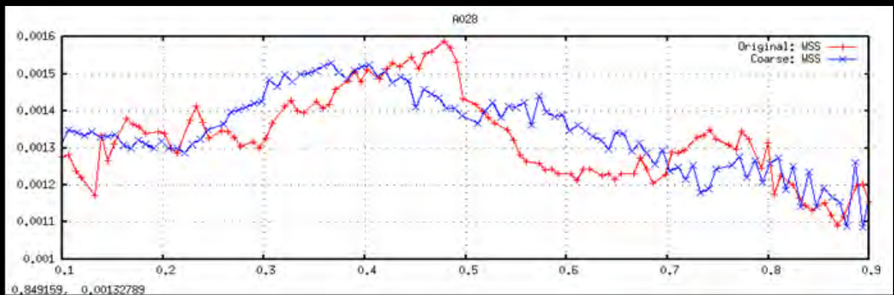


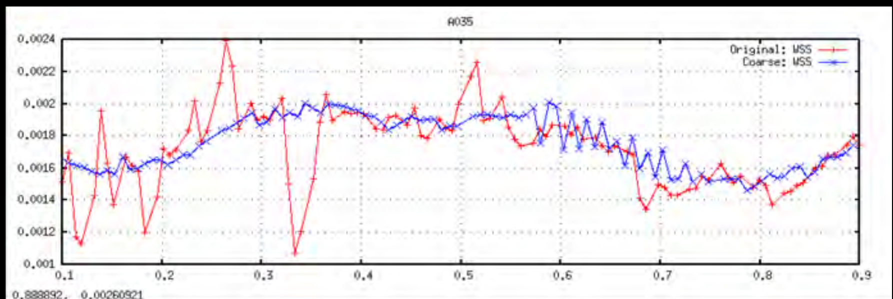
Patient cases can be classified in locations where the aneurysm developed



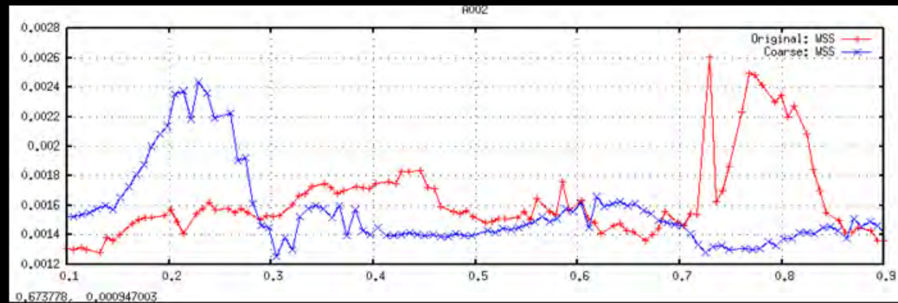


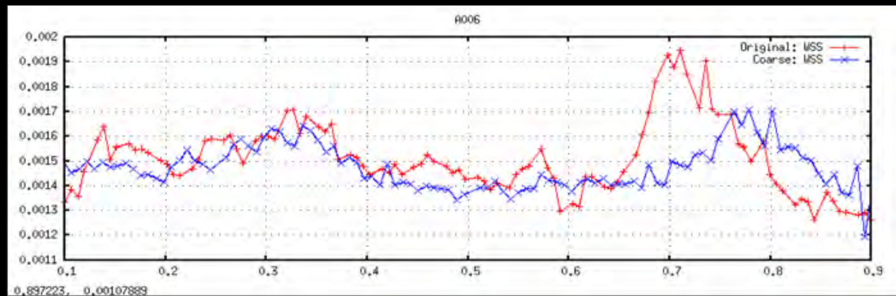


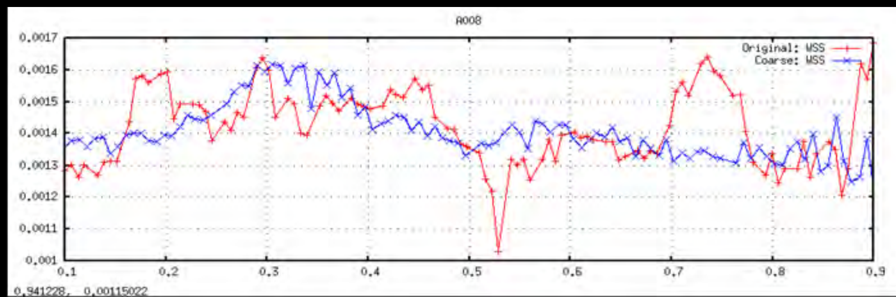




developed on aortic arch





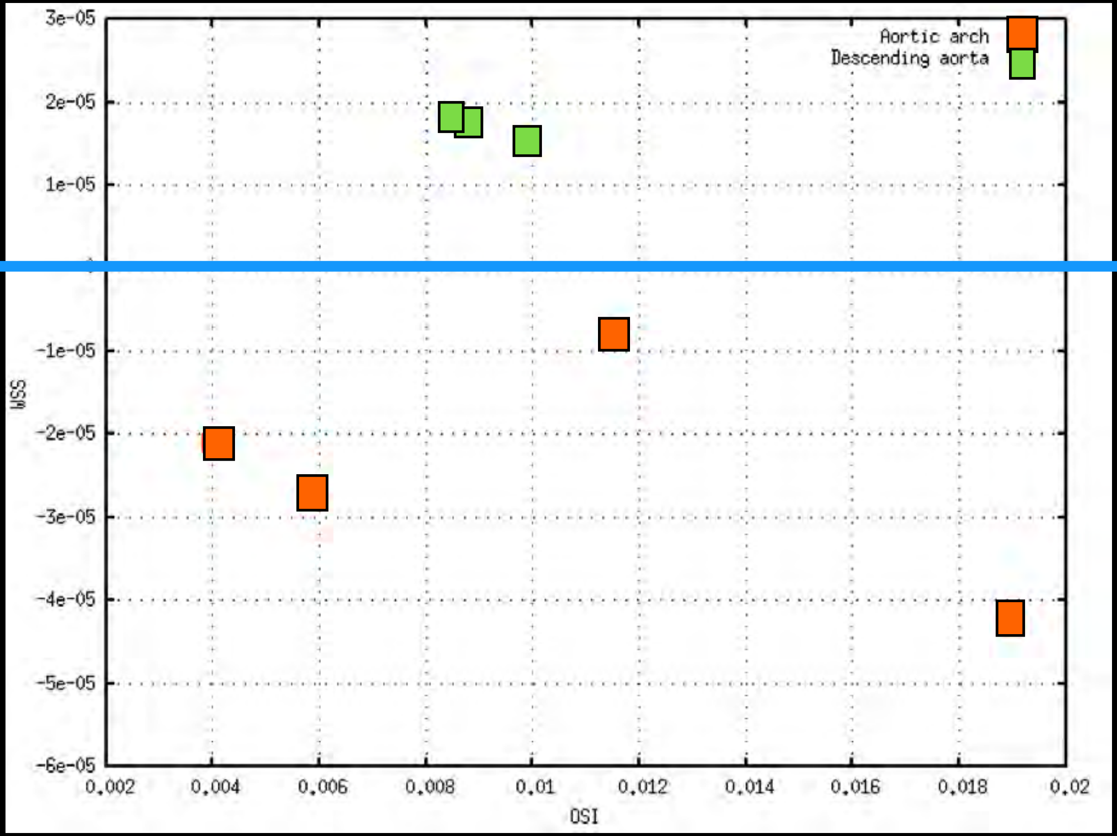


developed on descending aorta

Differences in WSSs and OSIs integrated along the centerlines between original and coarse grained shapes

WSS_original

- WSS_coarse

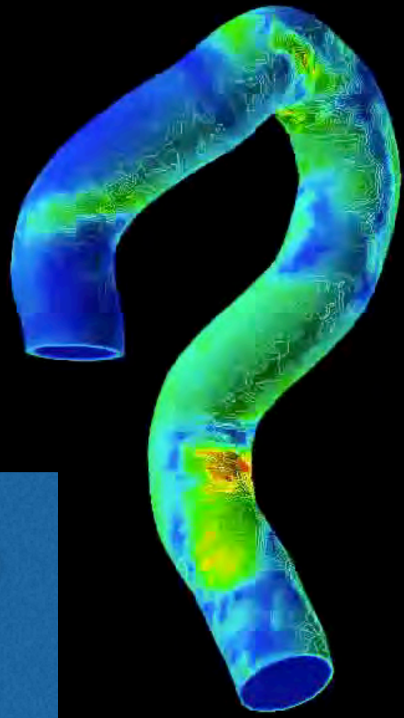


OSI_original - OSI_coarse

Patient cases with the aneurysms on the aortic arch

Patient cases with the aneurysms on the descending aorta

Conclusions



We have examined the relationship between aorta morphology and WSS distributions characteristics.

- Vortical flows in the aorta are strongly affected by the aorta morphologies.
- Torsion in the aortic arch breaks down the Dean's vortices, which makes WSS weaker.
- Clinically important characteristics of the aorta morphology can be represented by the difference between coarse-grained and original morphologies.

Difference among individuals for torsion : large

Difference among individuals for curvature : small