Correlation between wall shear stress and wall rupture properties in ascending thoracic aortic aneurysms

Prof. Stéphane AVRIL

44ème CONGRES SOCIETE DE BIOMECANIQUE
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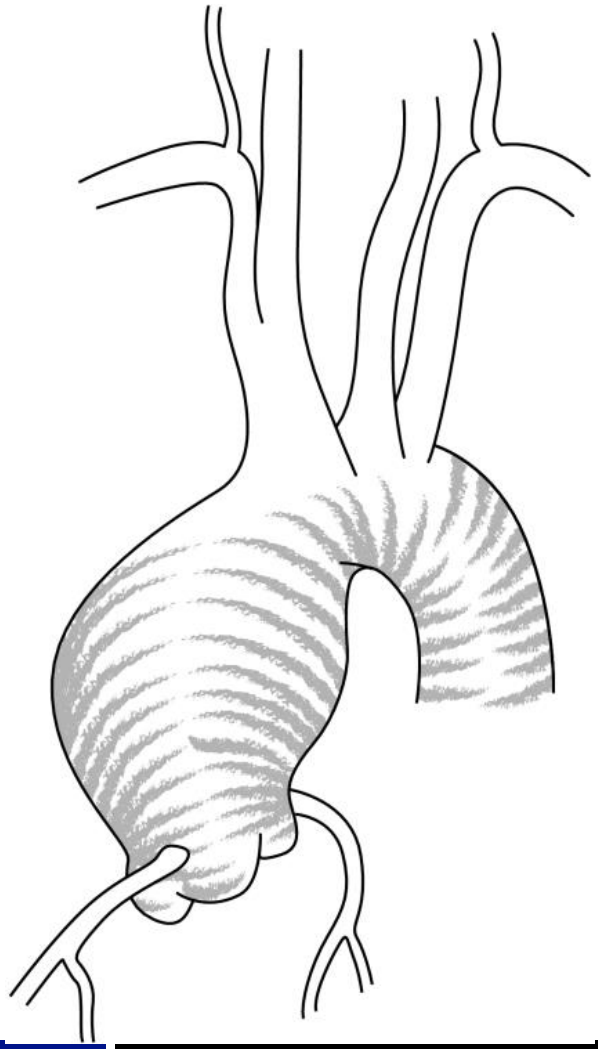
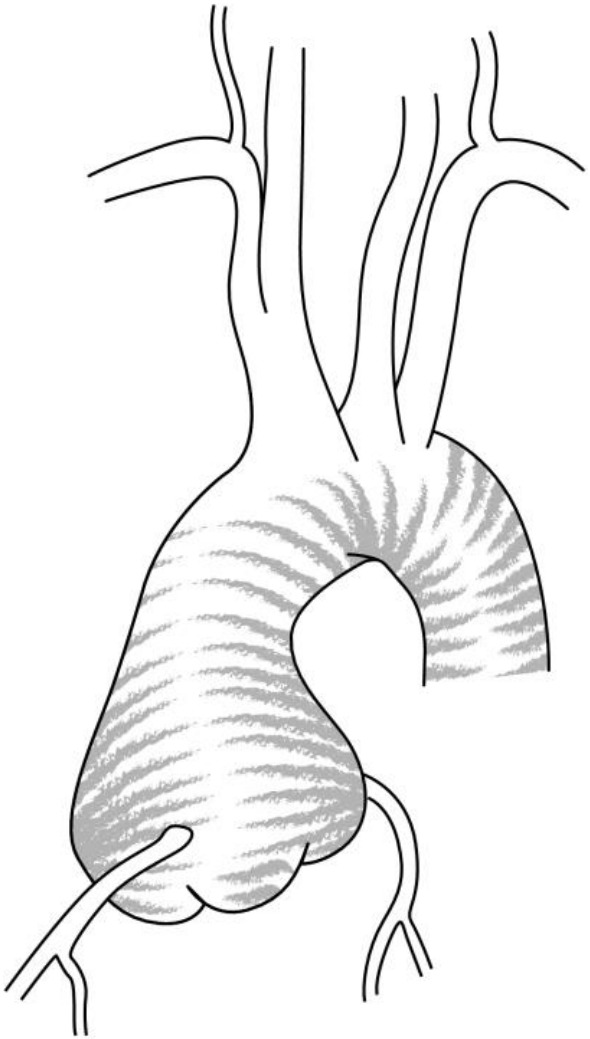
@SB2019Poitiers

Aortic root dilatations and ascending thoracic aortic aneurysms (ATAA)





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Risks: Aortic dissections

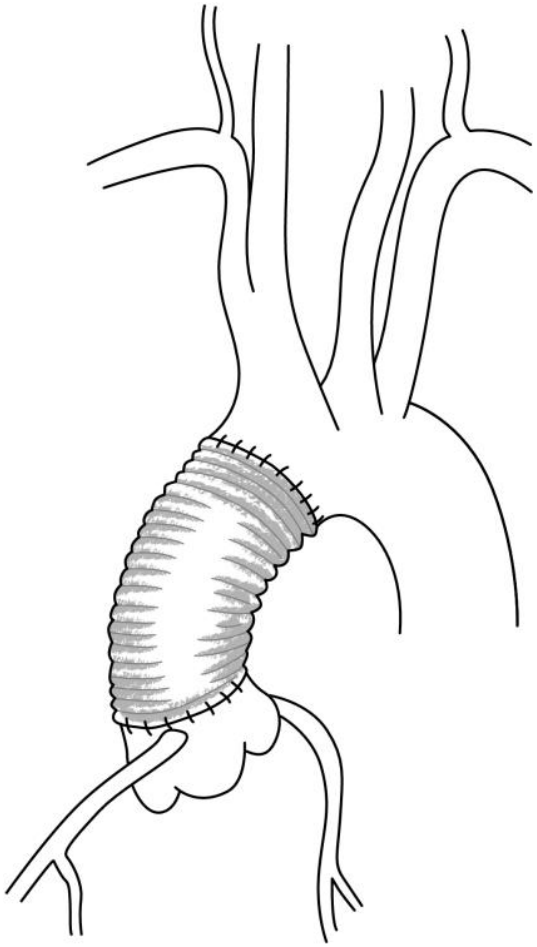
Surgical elective repair of ATAA

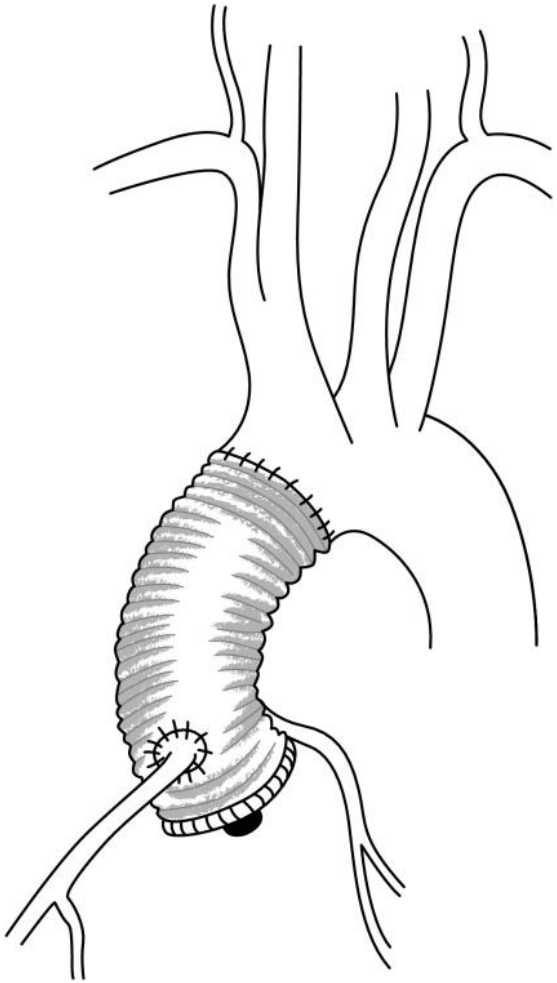
- Indications:
  - Aortic insufficiency requiring surgical correction
  - Size $\geqslant$55 mm
  - Size $\geqslant$50 mm in patients with Marfan syndrome or bicuspid valves
  - Growth rate $\geqslant$1 cm/year

- More and more aneurysms are detected at an early stage (incidence >8% for males >65 years old).

- >90000 interventions per year in Europe and USA

Surgical techniques for ATAA repair





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Current situation

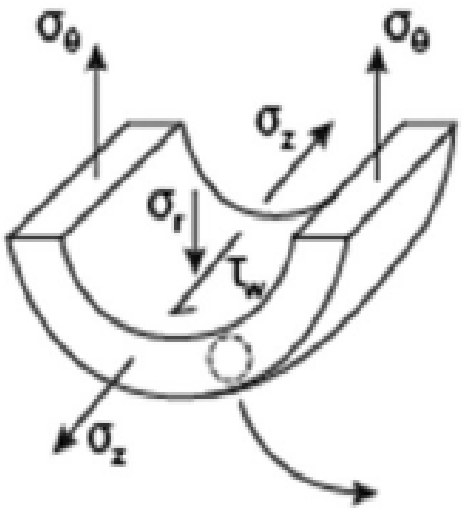
- **<u>Current indications</u>:**
  - 25% ATAA < 5.5cm rupture : 15000 deaths**!
  - 60% of ATAA > 5.5 cm never experience rupture!
  - 9% mortality and morbidity after ATAA repair

- **In summary: inappropriate decisions and misprogramed surgical interventions have major consequences!!**

- **Need insightful assistance from biomechanics ☺☺☺**

** Pape et al, *Aortic Diameter ≥5.5 cm Is Not a Good Predictor of Type A Aortic Dissection Observations From the International Registry of Acute Aortic Dissection (IRAD)*, Circulation, 2007

Basics of arterial mechanics

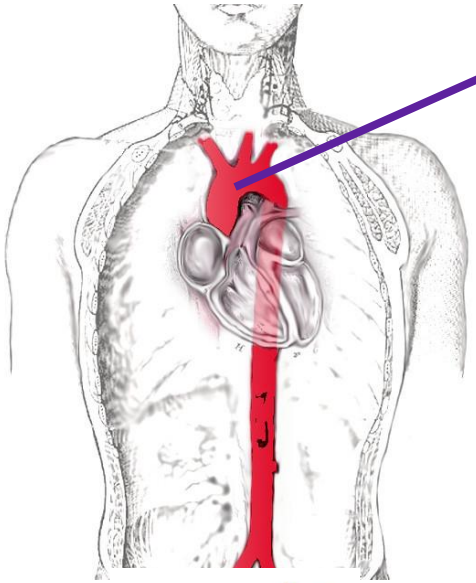


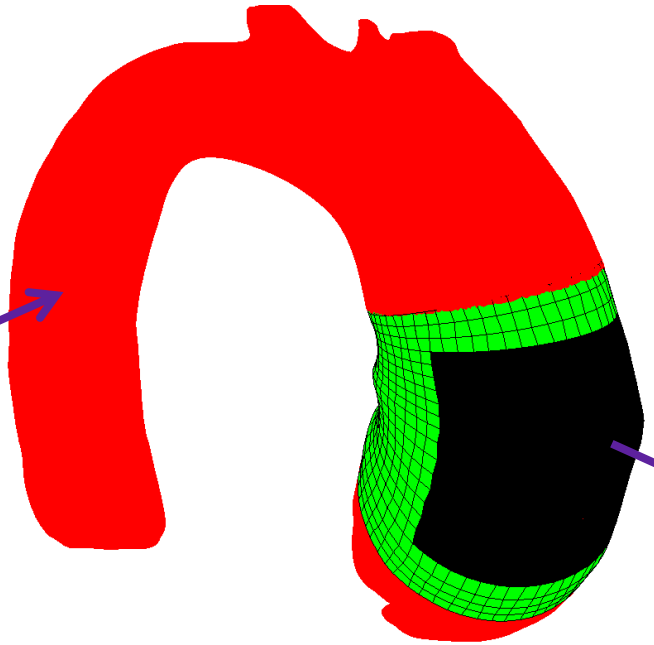
$$\tau_w = \frac{4\mu Q}{\pi a^3},$$

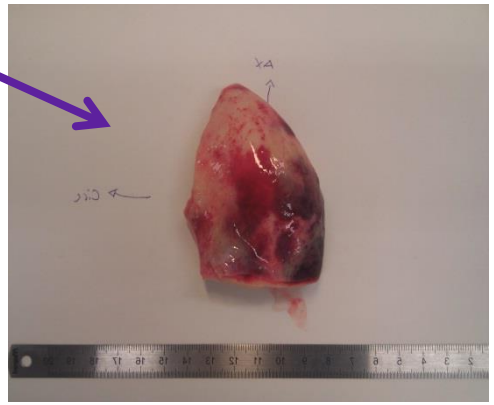
$$\boxed{\sigma_\theta = \frac{P a}{h}}$$

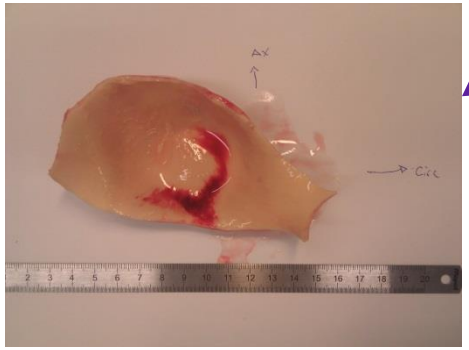
Humphrey JD (2002) *Cardiovascular Solid Mechanics: Cells, Tissues, and Organs*, Springer-Verlag, NY

Collection of the samples









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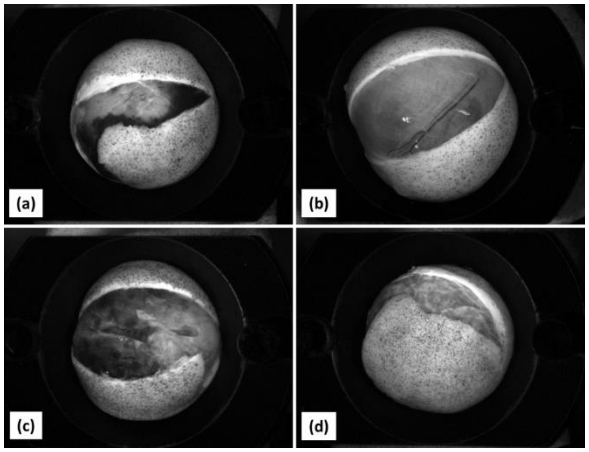
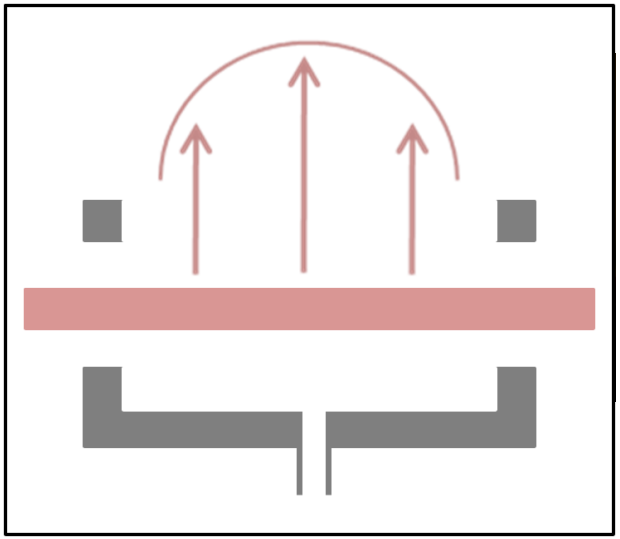
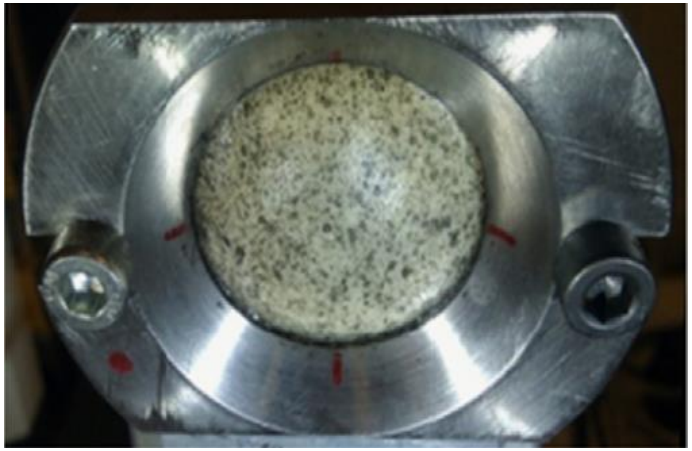
Bulge inflation test

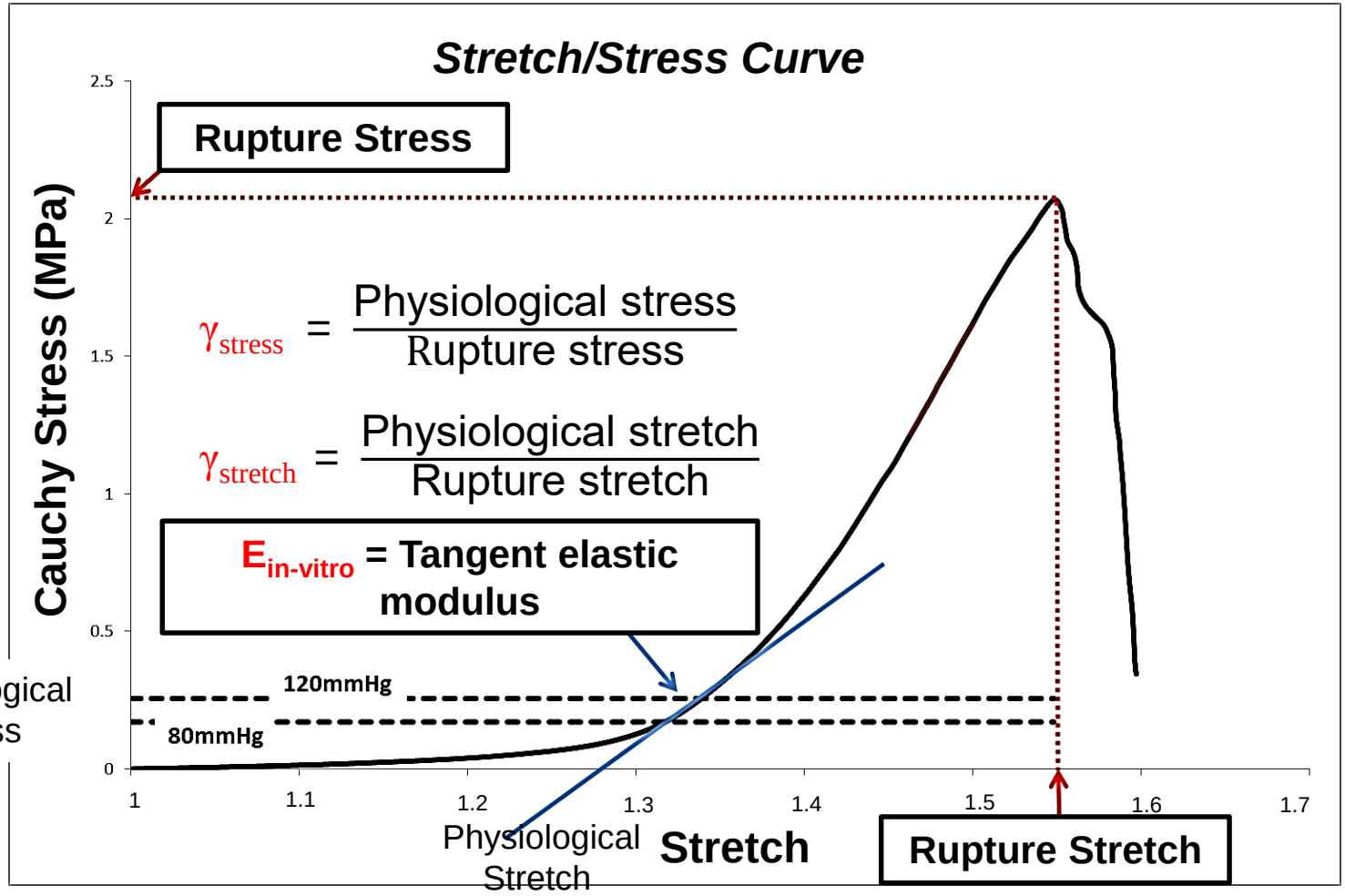
Romo et al. Journal of Biomechanics - 2014







Rupture risk estimation



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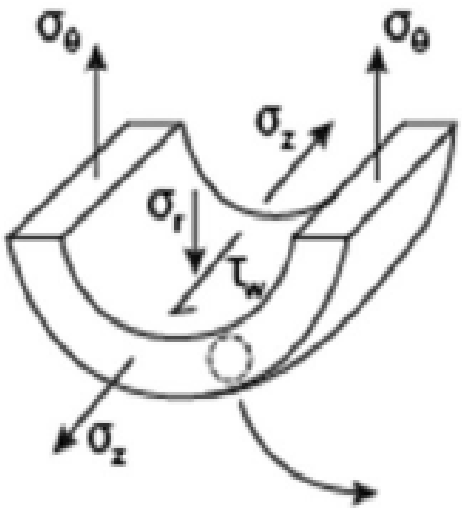

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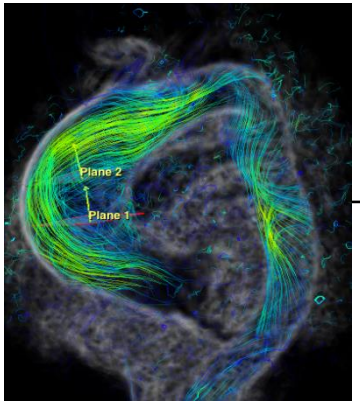
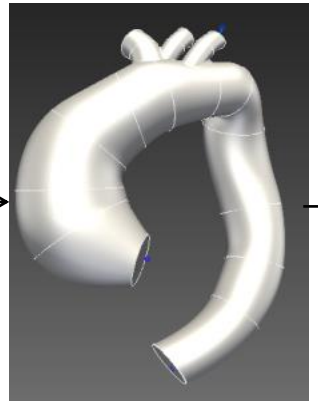
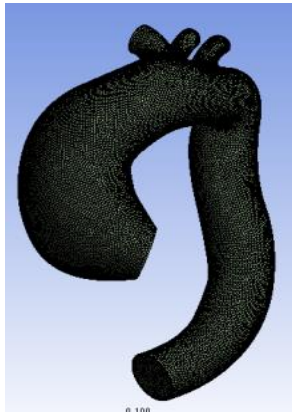
AORTIC HEMODYNAMICS ASSESSMENT



Preoperative dynamic imaging 4D MRI

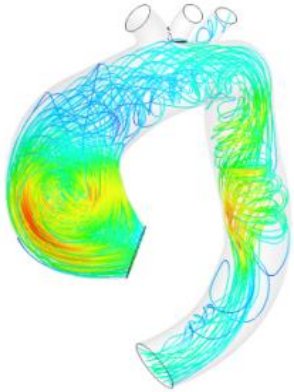


CAD



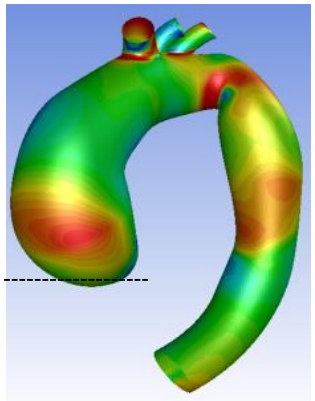
Mesh

Numerical Solution



Streamlines, velocity

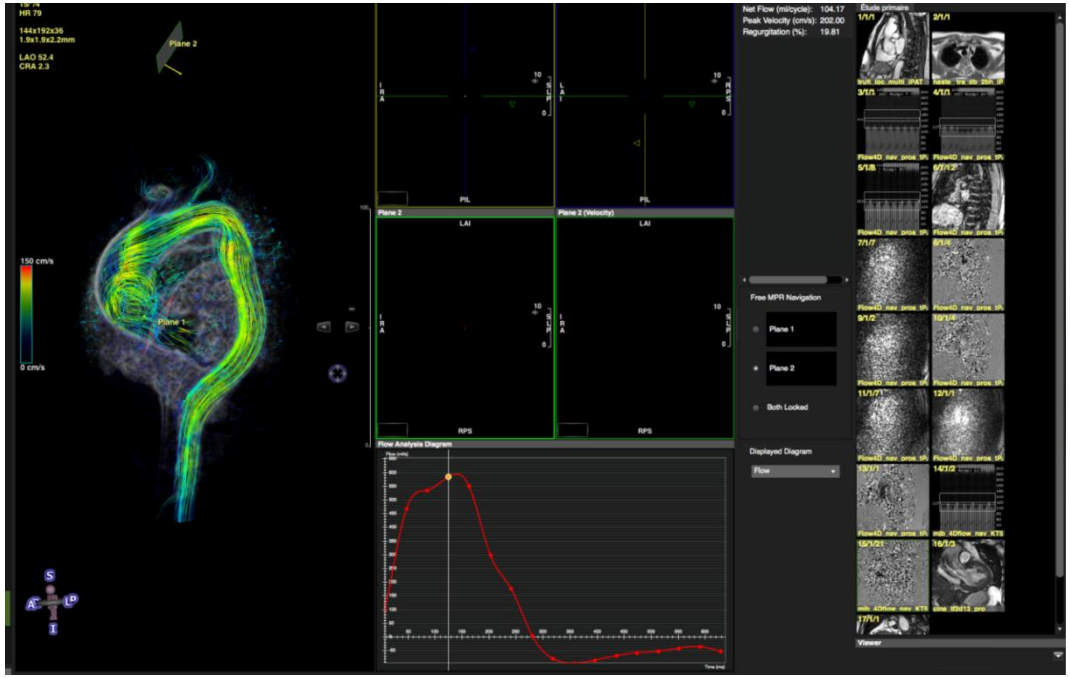
TAWSS



4D MRI images - Pre-processing

Siemens 3T Prisma

circle CARDIOVASCULAR IMAGING



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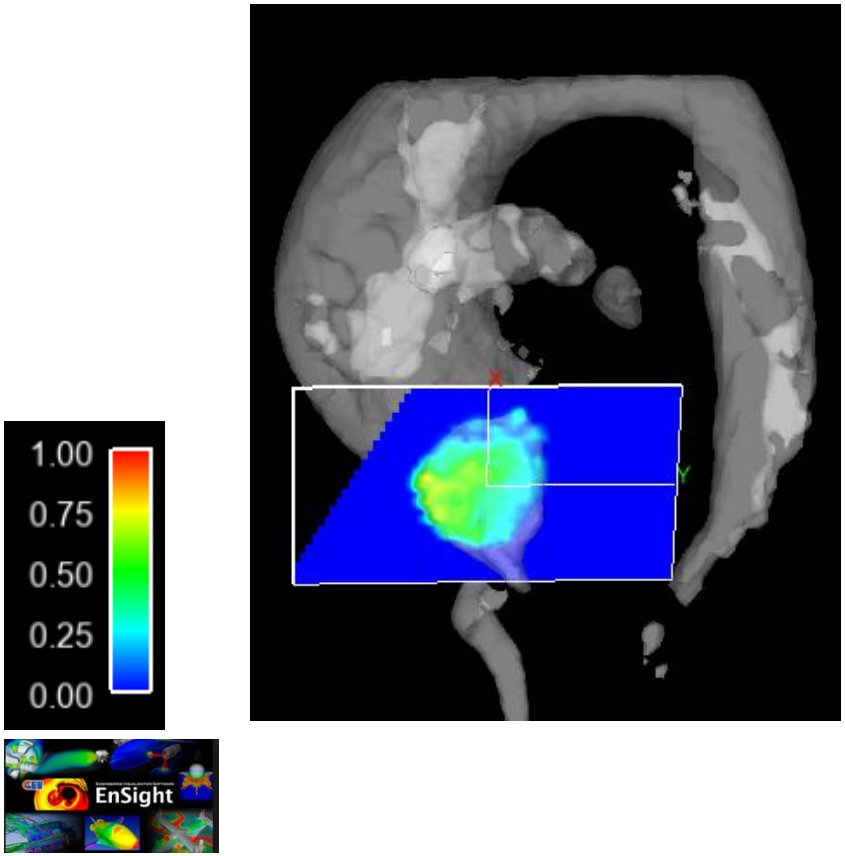
MINES Saint-Étienne

Patient Specific BCs - Velocity profile mapping

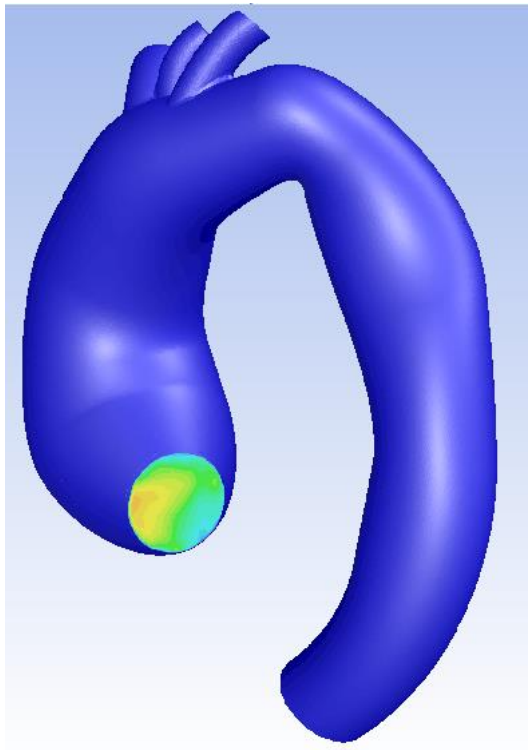
4D MRI data Velocity Profile



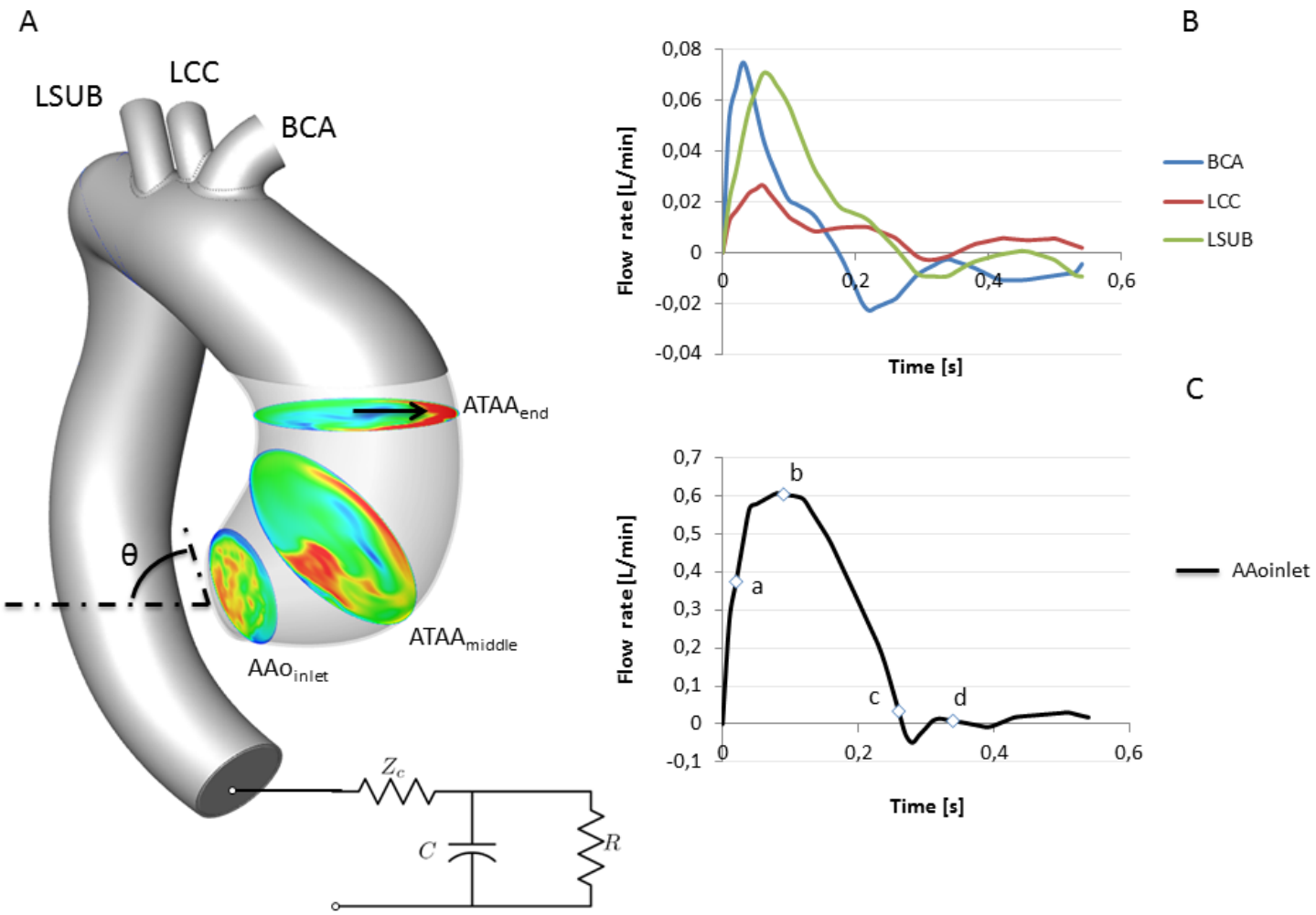
MATLAB

ANSYS FLUENT

CFD Velocity Profile



CFD - Numerical resolution



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Hemodynamics indices

Time averaged wall shear stress (WSS):

$$TAWSS = \frac{1}{T}\int_0^T WSS\, dt$$

Oscillatory Shear Index:

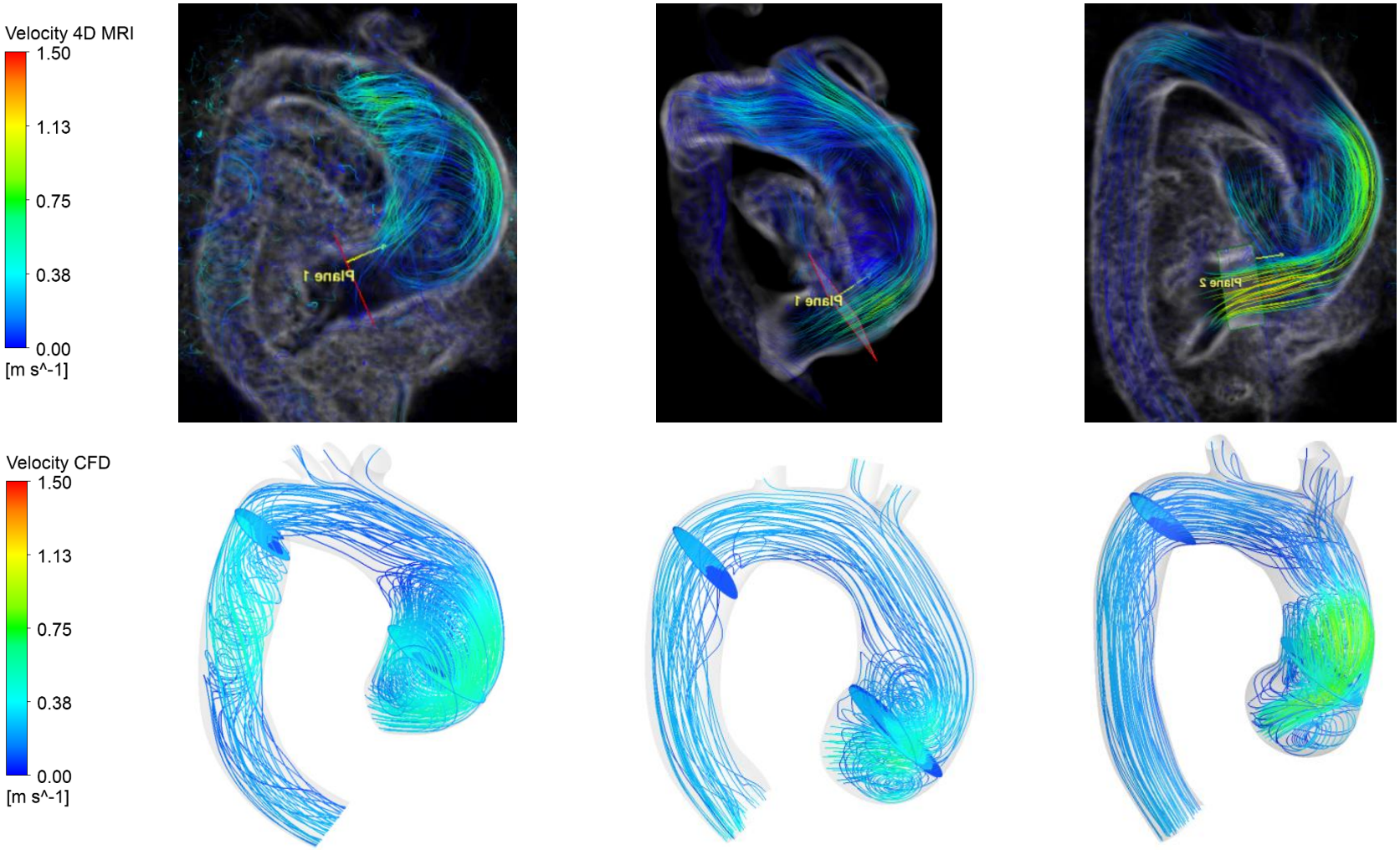
$$OSI = 0.5\left[1 - \left(\frac{\left|\int_0^T WSS(s,t)\cdot dt\right|}{\int_0^T |WSS(s,t)|\cdot dt}\right)\right]$$

where T is the period of the cardiac cycle and WSS is the instantaneous wall shear stress.

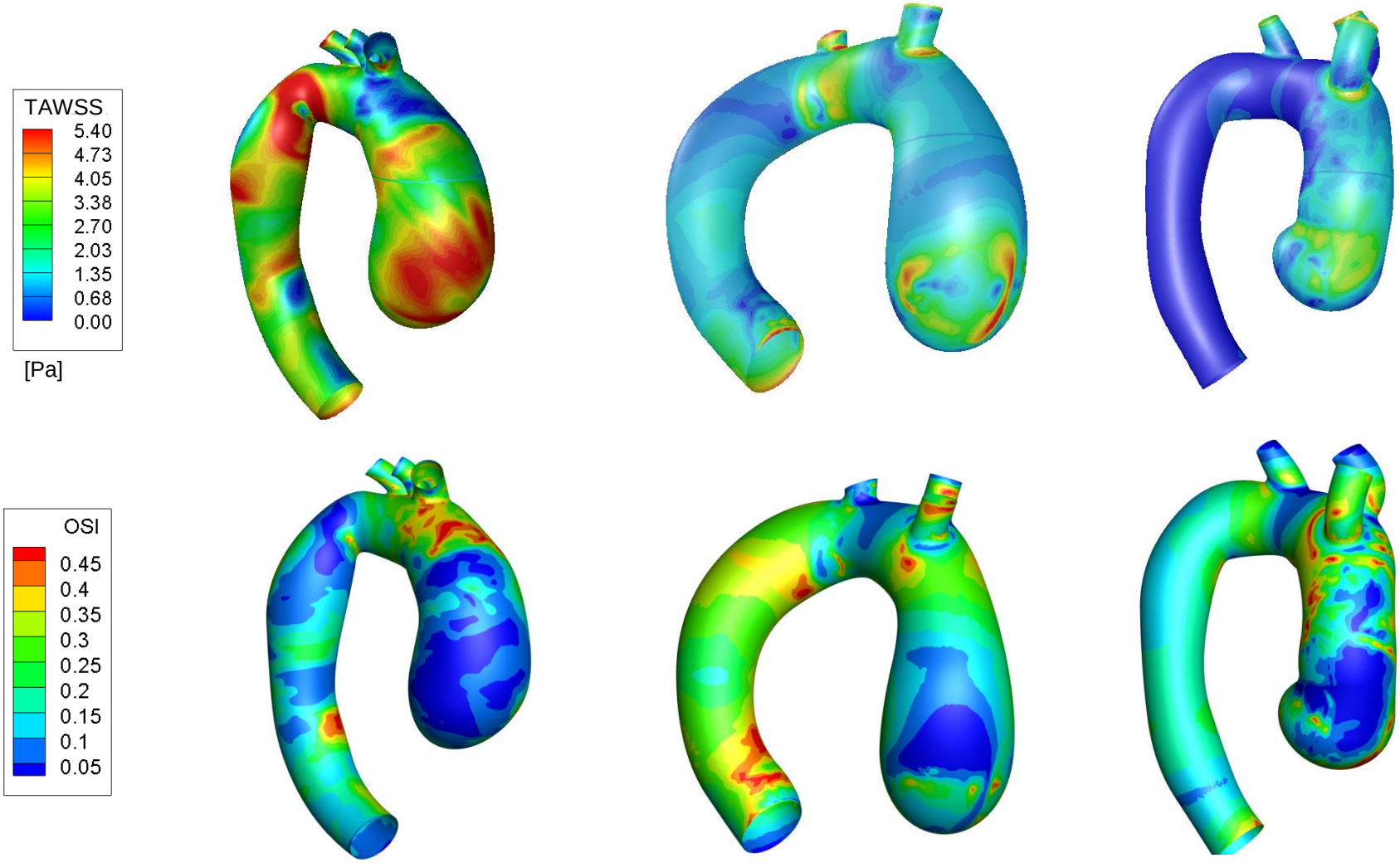
Morbiducci, U., R. Ponzini, G. Rizzo, M. Cadioli, A. Esposito, F.M. Montevecchi, A. Redaelli. Mechanistic insight into the physiological relevance of helical blood flow in the human aorta: an in vivo study. Biomech. Model. Mechanobiol. 10:339–355, 2011.

Velocity profiles

Patient 1 (BAV) **Patient 2 (TAV)** **Patient 3 (BAV)**



OSI and TAWSS



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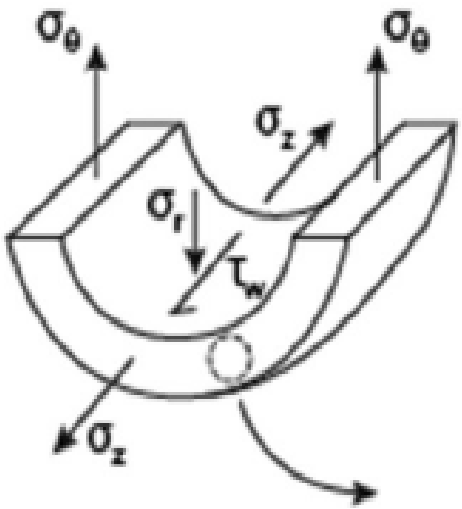

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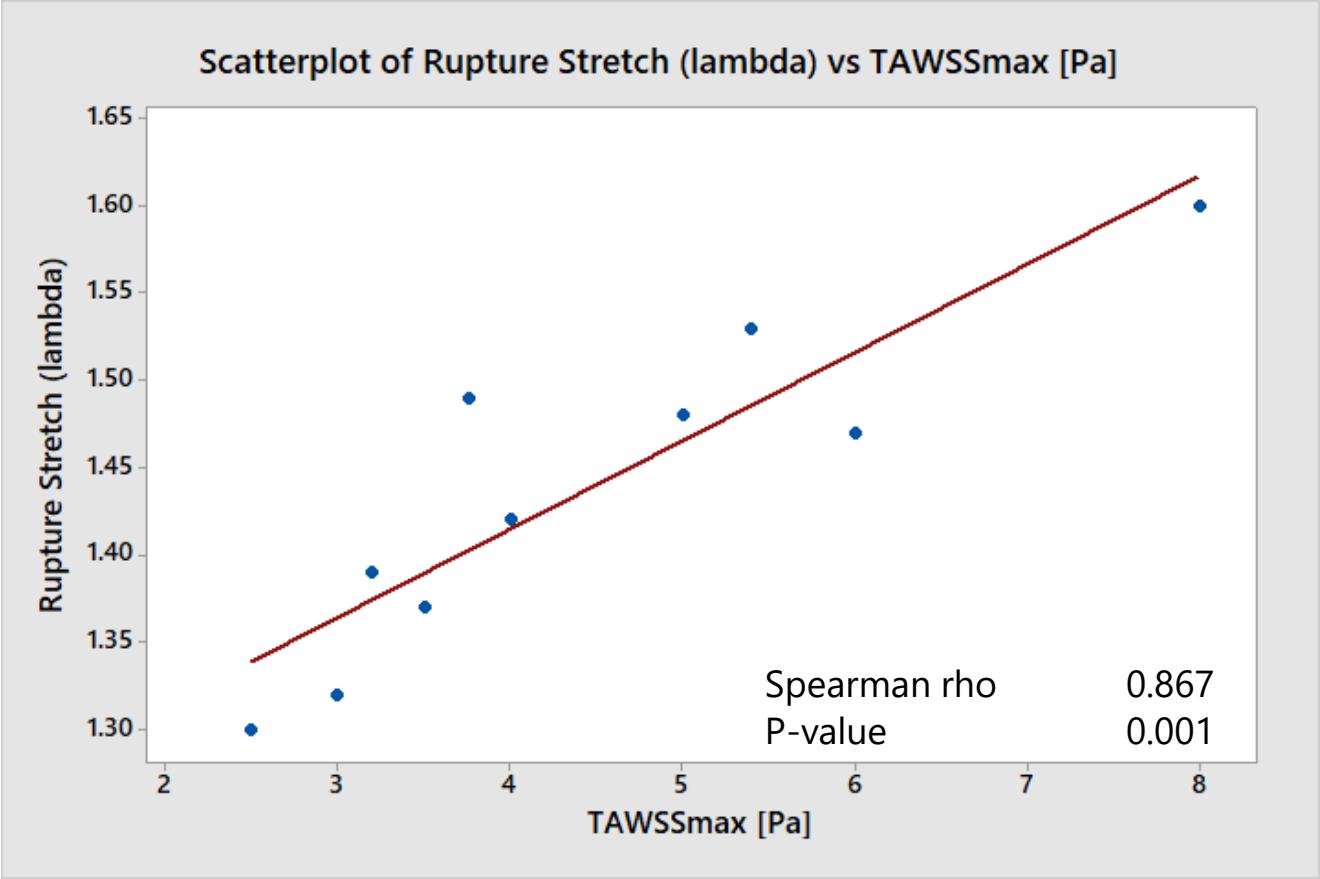
Statistical Analysis-Spearman Rho: $\lambda_{rupture}$ vs. TAWSSmax [Pa]

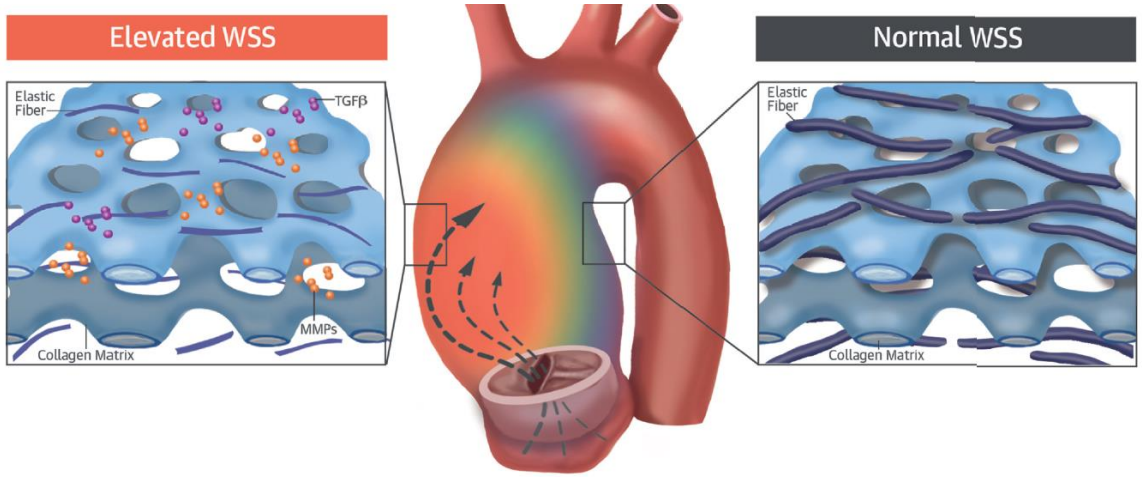


Condemi et al, IEEE Transactions on Biomedical Engineering, 2019

DISCUSSION

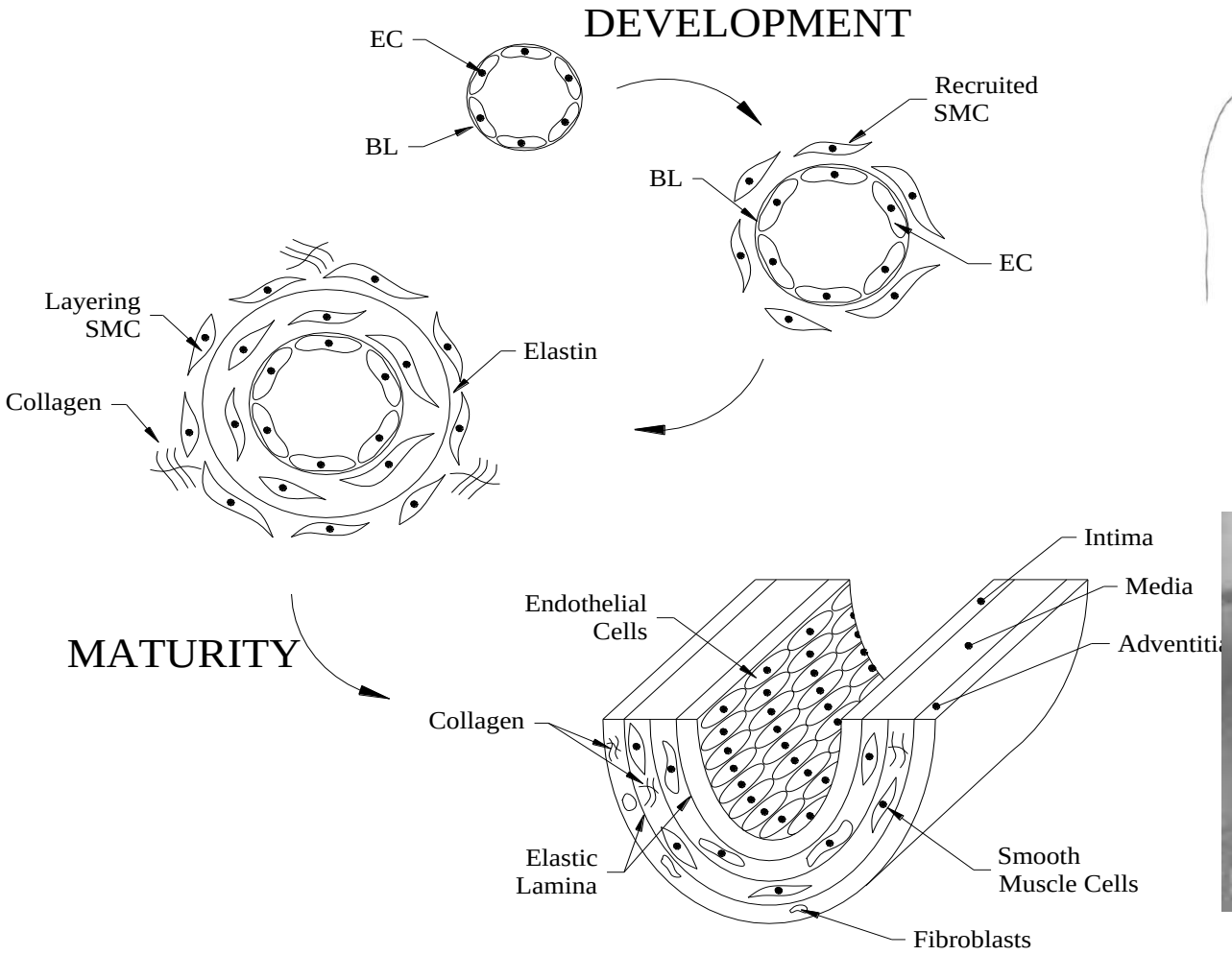
- **Protective role of larger TAWSS, associated with low oscillatory wall shear stress?**

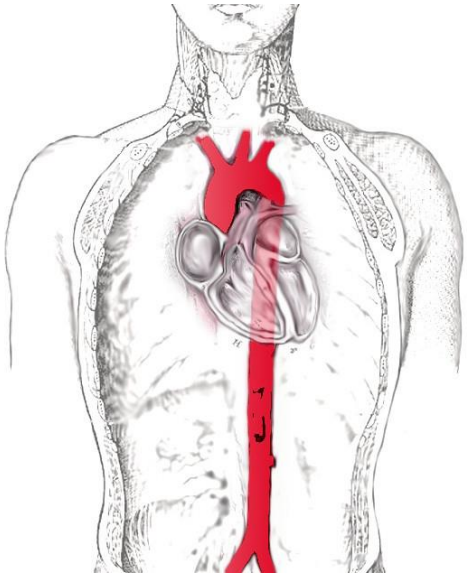
- **Controversial effects**

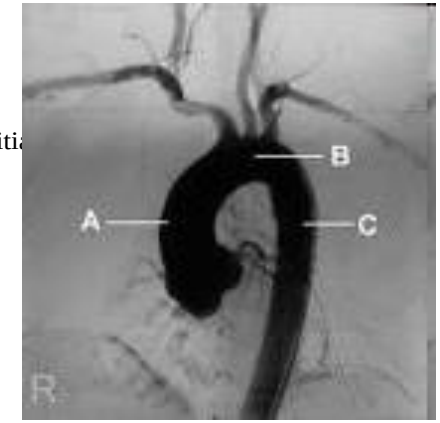


Guzzardi et al. JACC 2015

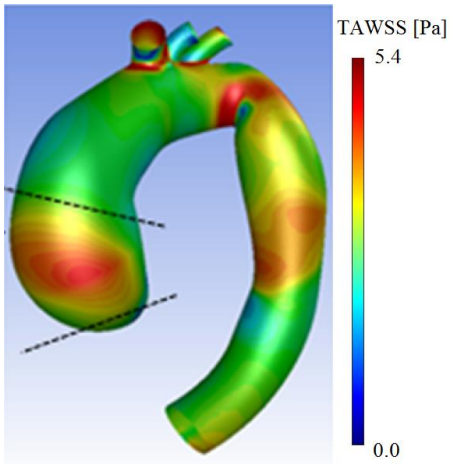
Modeling of mechanobiological processes





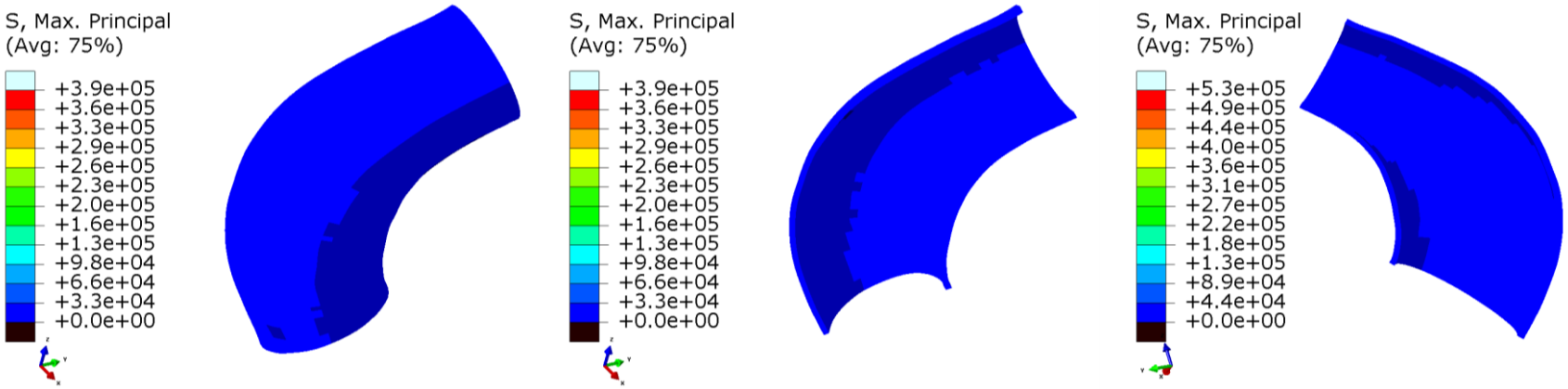


Patient-specific predictions



Growth and remodeling of a two–layer patient–specific human ATAAs due to elastin loss

Small growth parameter



Maximum Principal stress

Mousavi et al, BMMB 2019

SUMMARY

- ATAA at higher “biomechanical” risk have an increased stiffness and a disturbed flow with reduced maximum TAWSS

- Our future work will focus on idiopathic ATAA and try to understand better what are the main triggers for the overstiffening.

avril@emse.fr

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