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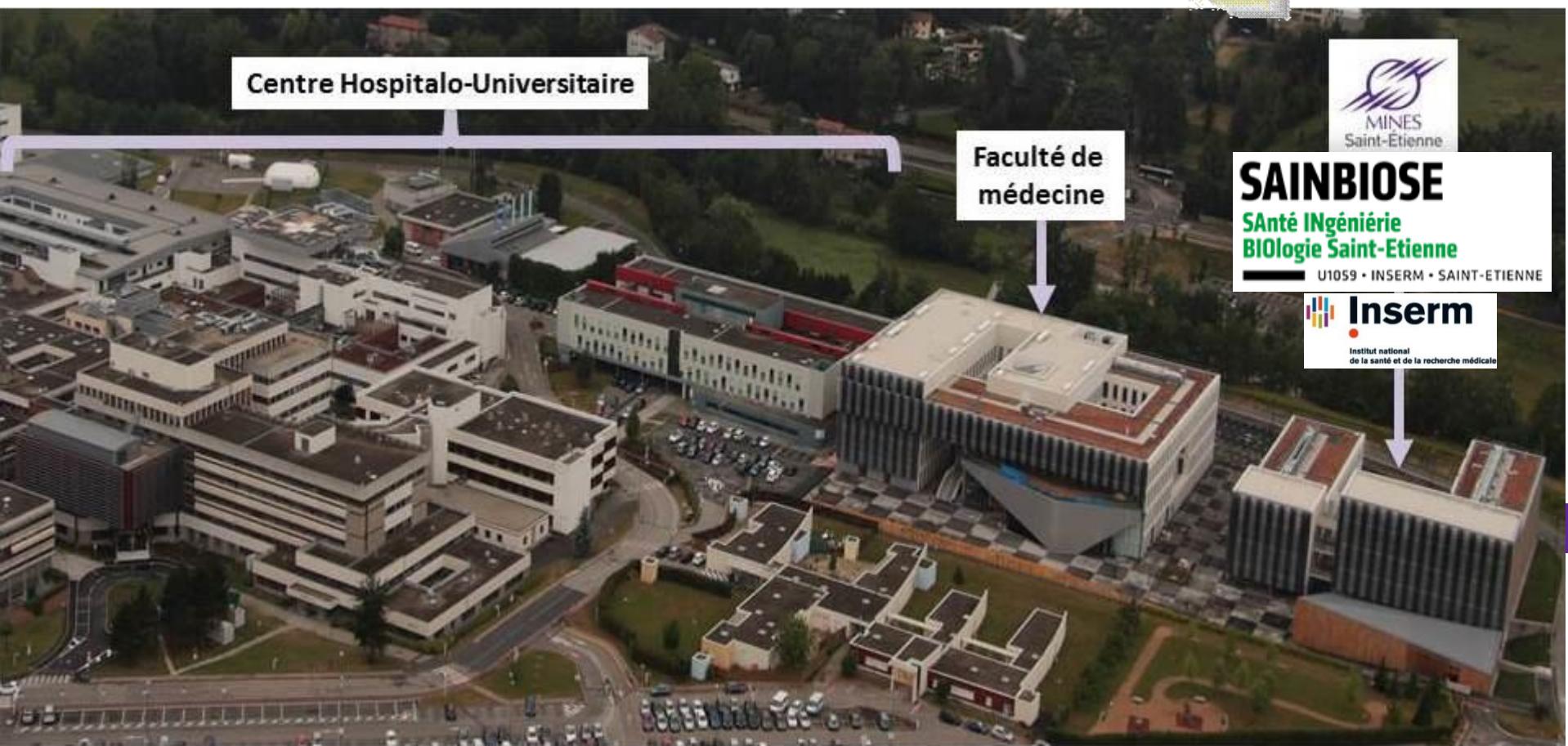
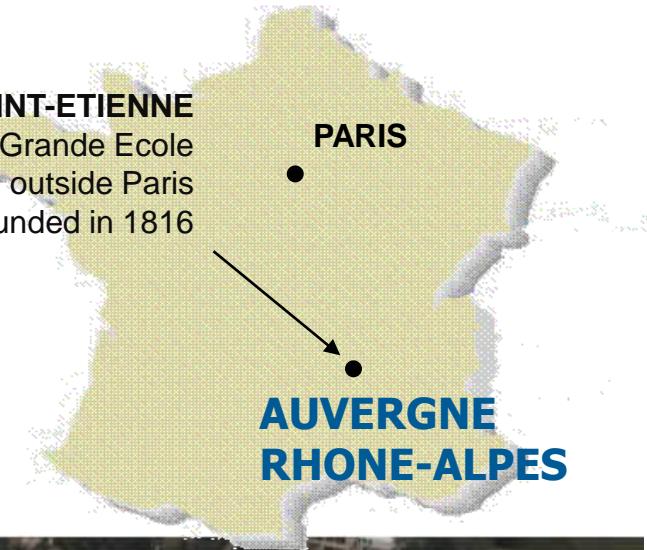
***Fluid structure interactions  
in ascending thoracic  
aortic aneurysms***



Prof. Stéphane AVRIL



**MINES SAINT-ETIENNE**  
First Grande Ecole  
outside Paris  
Founded in 1816



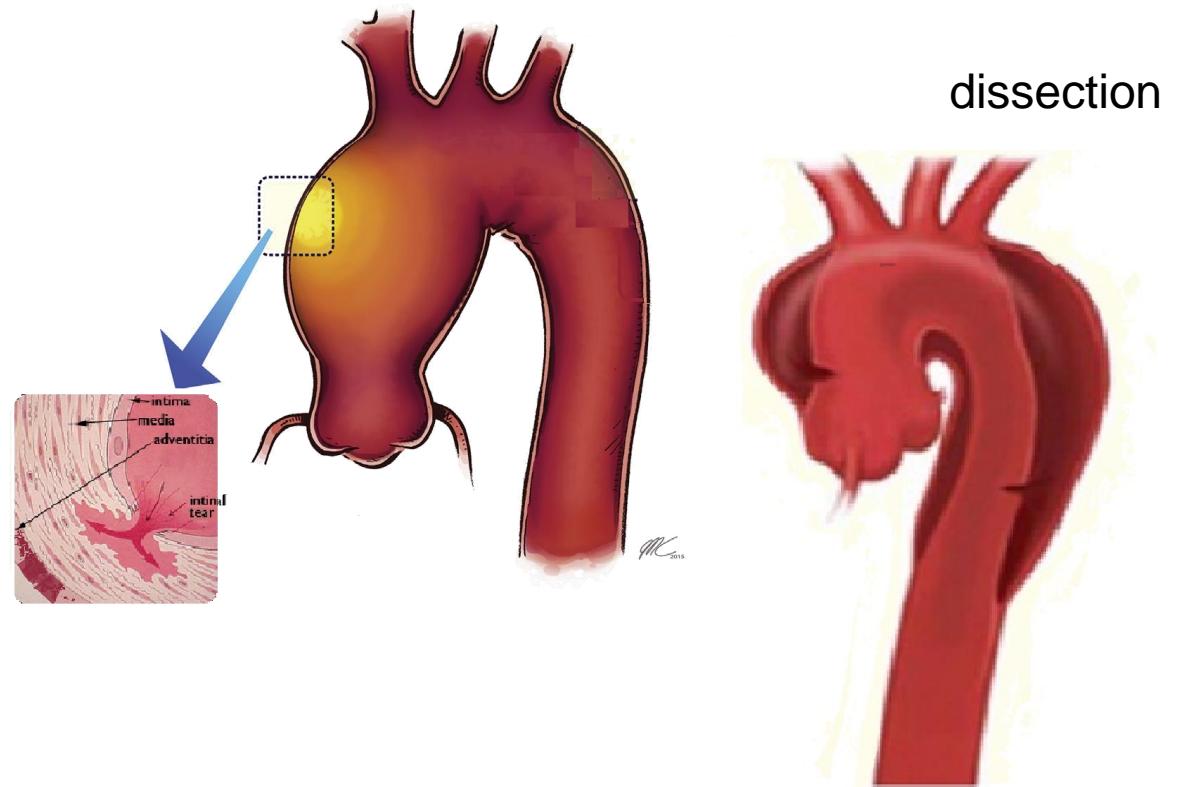
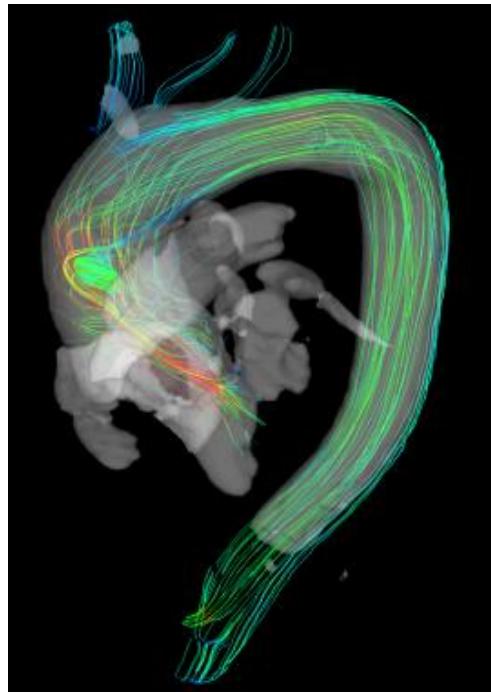
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# Prediction of risk of rupture and dissection



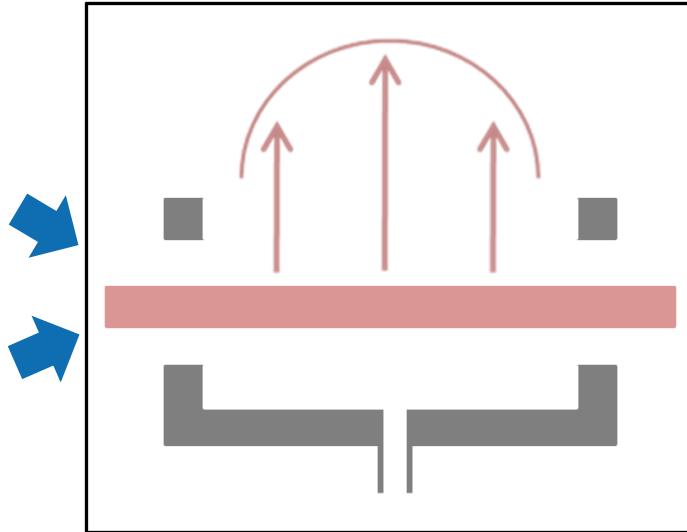
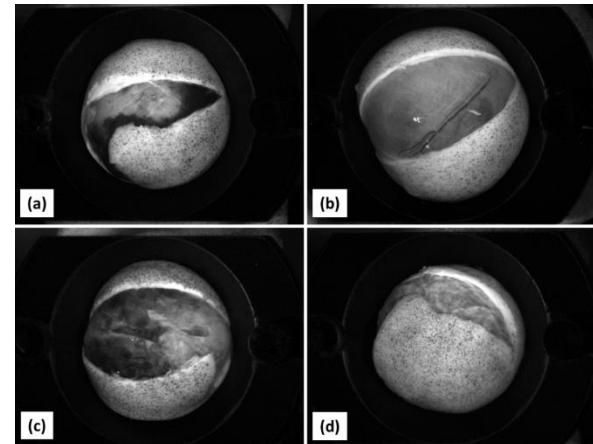
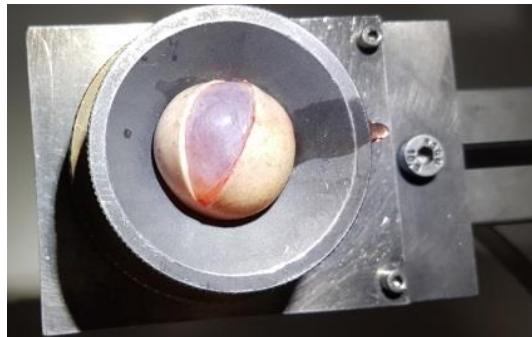
# Context

- **More and more aneurysms are detected at an early stage (incidence >8% for males >65 years old).**
- **An intervention is recommended if the aneurysm grows more >1cm/year or it is >5.5cm. This represents >90000 interventions per year in Europe and USA**
- **BUT:**
  - 25% aneurysms <5.5cm rupture : 15000 deaths\*\*!
  - 60% of aneurysms >5.5 cm never experience rupture!
- **In summary: very high rate of inappropriate decisions and misprogrammed surgical interventions!!**

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

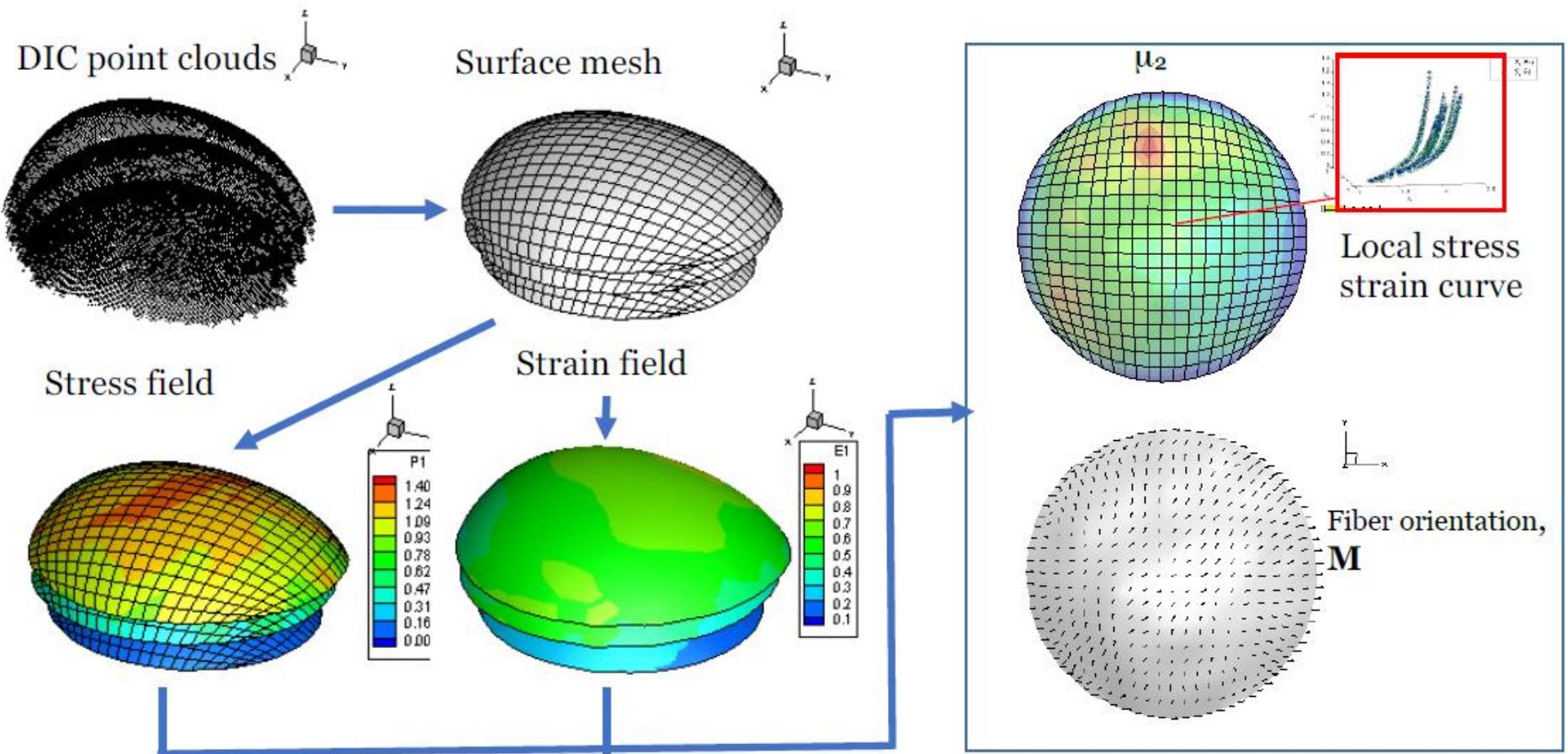
# Bulge inflation test

Romo et al. Journal of Biomechanics -  
2014

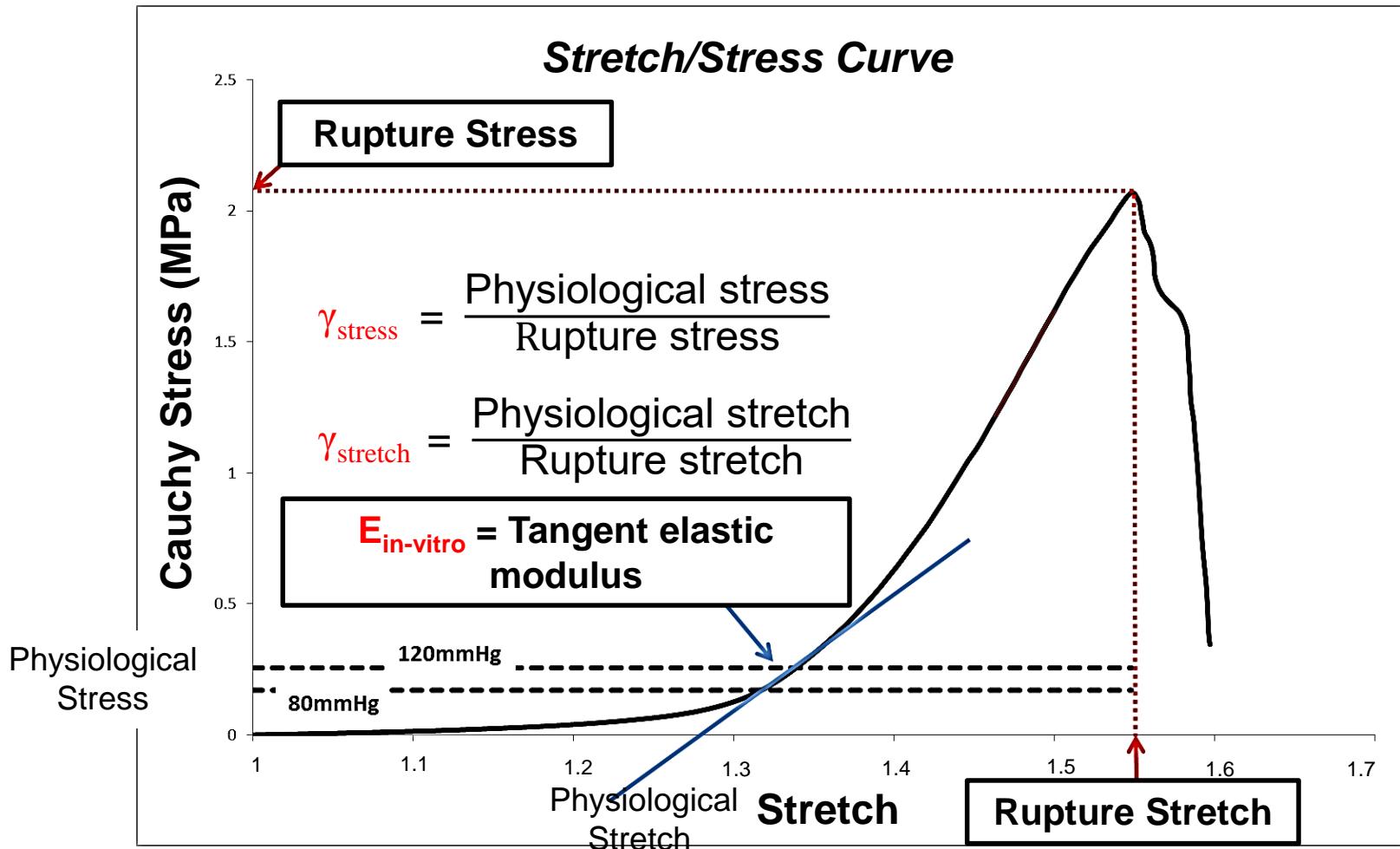




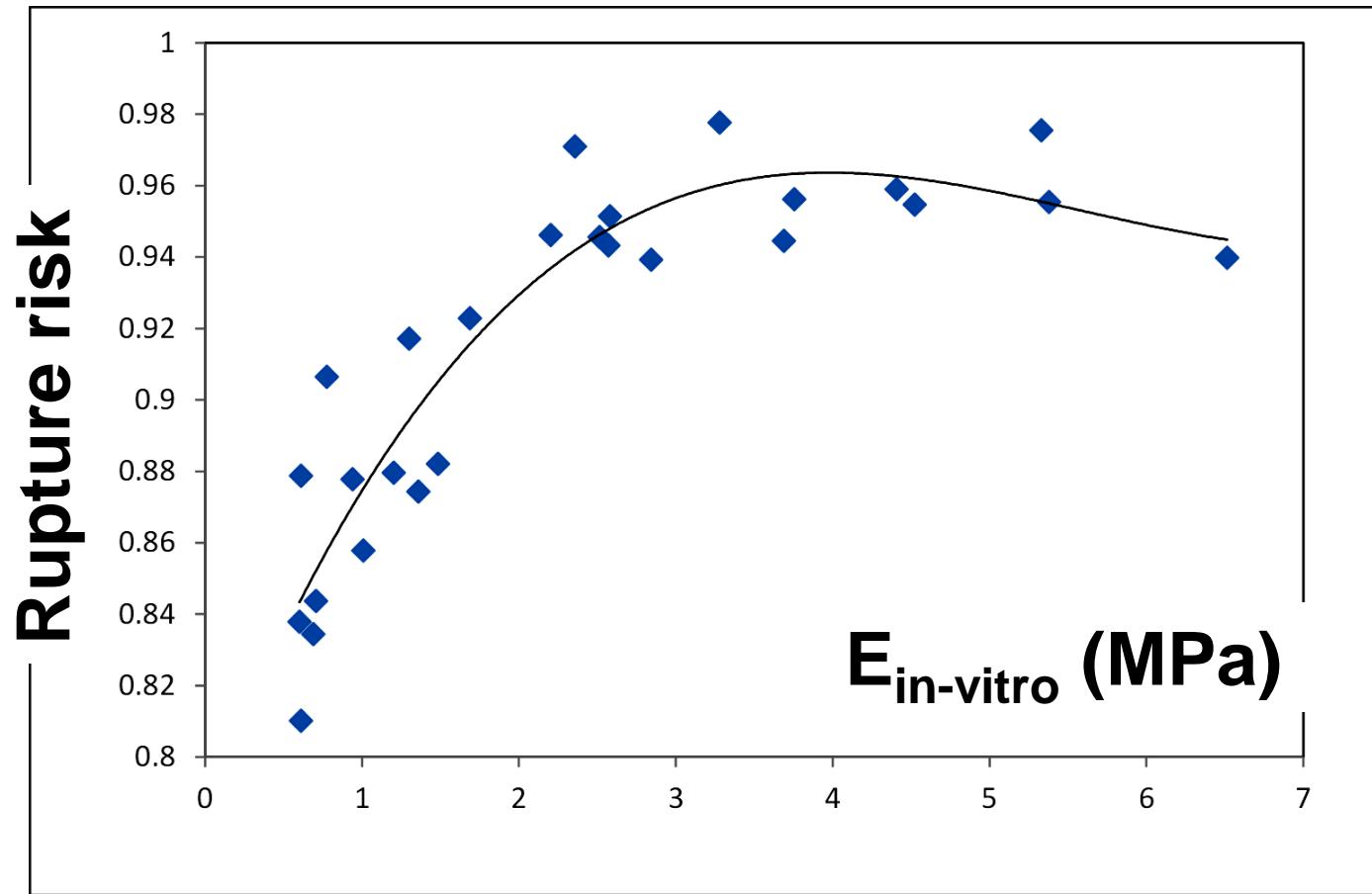
# Identification of local material properties



# Rupture risk estimation



# Correlation between the stretch-based rupture risk and the tangent elastic modulus

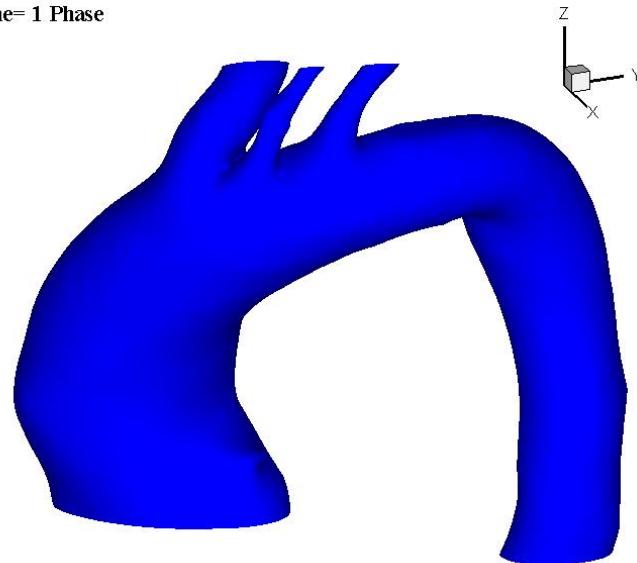


Duprey A, et al. Biaxial rupture properties of ascending thoracic aortic aneurysms. *Acta Biomaterialia* 2016.

# Relationship with aortic stiffness?

Is the stretch based rupture risk criterion correlated to the aortic stiffness which could be measured by elastography techniques?

Time= 1 Phase



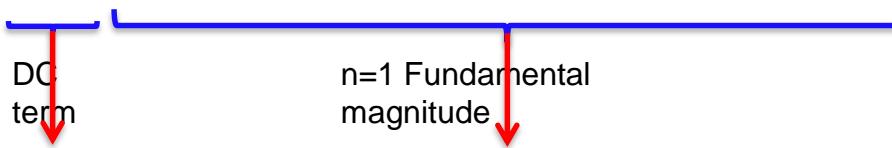
Olfa Trabelsi, Miguel A Gutierrez Cambron, Solmaz Farzaneh, Ambroise Duprey, Stéphane Avril. A non-invasive methodology for ATAA rupture risk estimation. *Journal of Biomechanics* 2017.

# Methodology

## Discrete Fourier transform of the aortic deformation at every position

- STL files of 10 Phases for each patient
- Structural mesh for all phases
- Mesh morphing function between the geometries of each phase
- Writing the coordinates of all phases

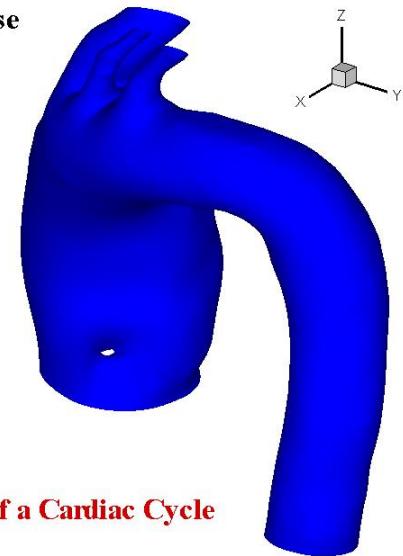
$$x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos(nft) + \sum_{n=1}^{\infty} b_n \sin(nft)$$



Average geometry

Displacements over a cardiac cycle

Time= 1<sup>th</sup>Phase



Ten Phases of a Cardiac Cycle

# Equation of local membrane stiffness

$$Q = \frac{\Delta P + \frac{\tau_1^0 \Delta r_1}{(r_1^0)^2} + \frac{\tau_2^0 \Delta r_2}{(r_2^0)^2}}{\frac{\varepsilon_1(t) + \nu \varepsilon_2(t)}{r_1^0} + \frac{\nu \varepsilon_1(t) + \varepsilon_2(t)}{r_2^0}}$$

$$\Delta P = \frac{\Delta P_0}{2} = \frac{P_{sys} - P_{dia}}{2}$$

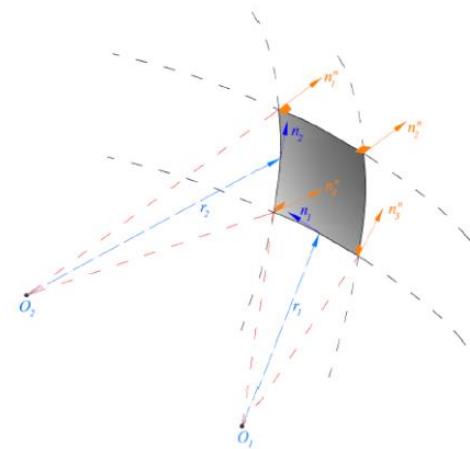
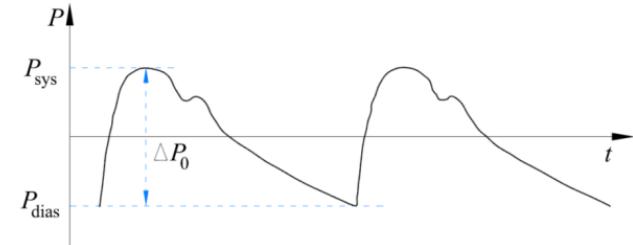
$r_1^0, r_2^0$ : Circumferential and longitudinal radii of curvature in average geometry

$\Delta r_1, \Delta r_2$ : Fundamental circumferential and longitudinal radii of curvature

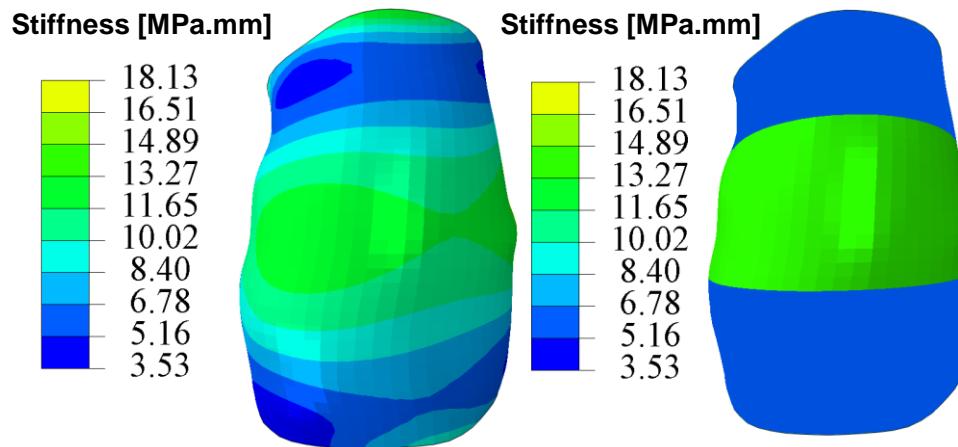
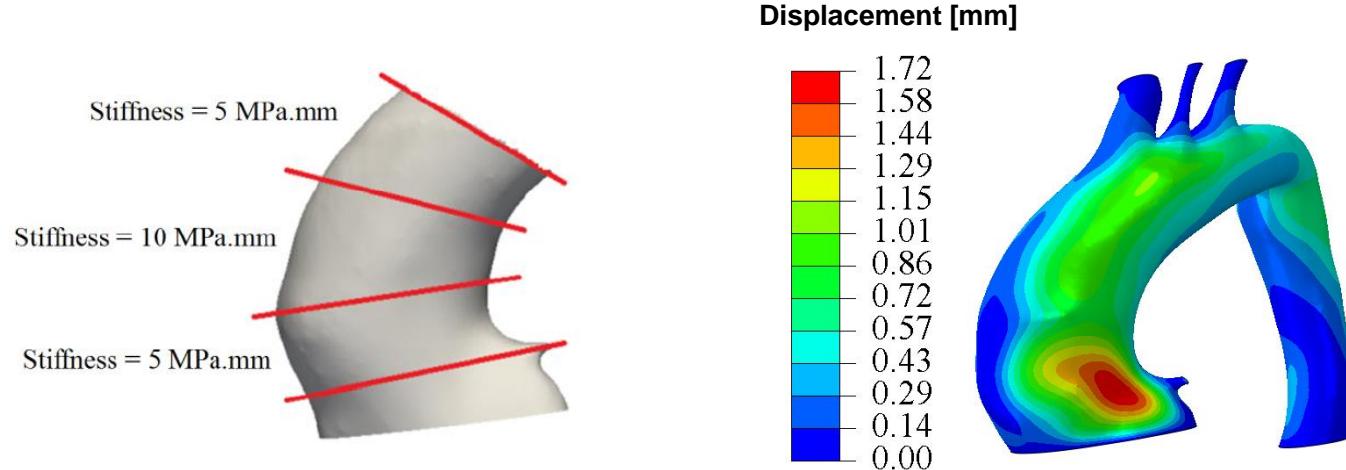
$\varepsilon_1, \varepsilon_2$ : Circumferential and longitudinal strains

$\tau_1^0, \tau_2^0$ : Pretensions in circumferential and longitudinal directions

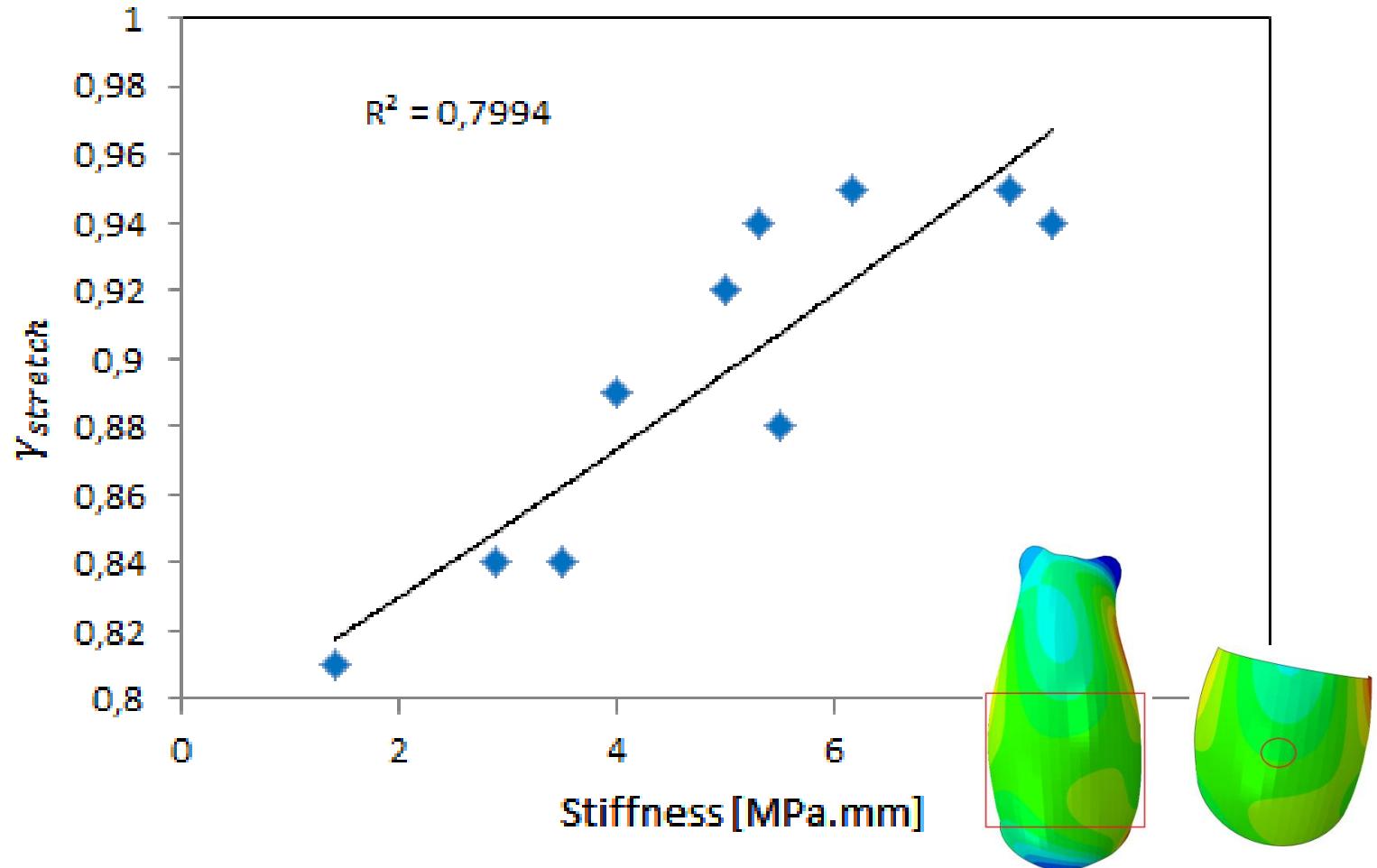
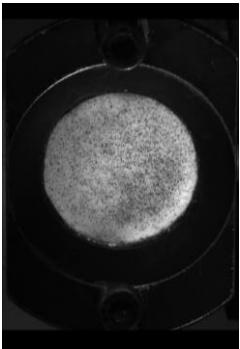
Farzaneh et al, BMMB 2018



# Validation



# Results



Farzaneh et al, ABME 2018

avril@emse.fr

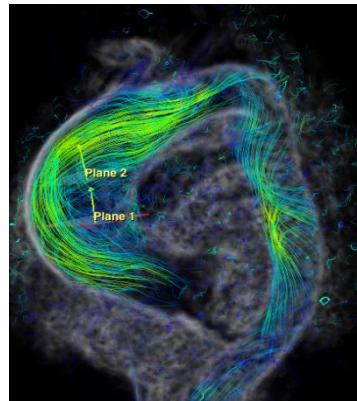
# Summary

- 2 ways of defining rupture:
- PWS – but unknown patient-specific strength
- $\gamma_{\text{stretch}}$  correlated with in vivo circumferential stiffness

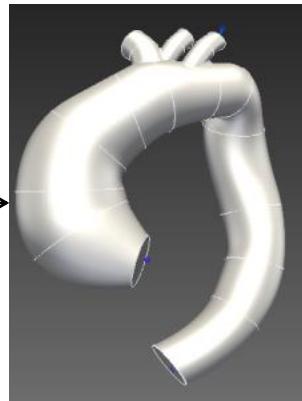
Higher stiffness  $\Rightarrow$  less risk because the aneurysm can more easily withstand volume variation



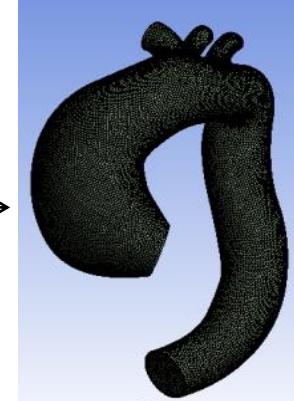
# RELATIONSHIP WITH HEMODYNAMICS



Preoperative dynamic imaging  
4D MRI

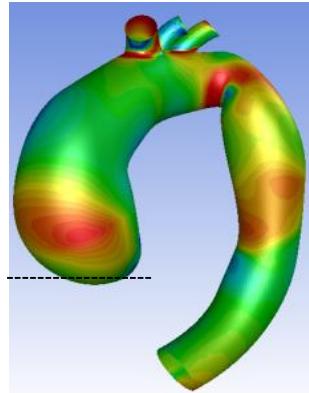


CAD

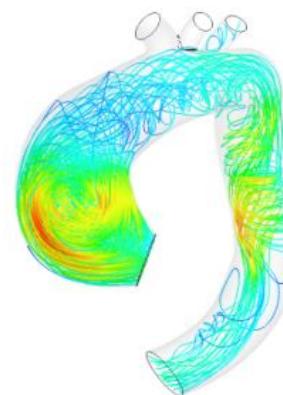


Mesh

Numerical  
Solution



TAWSS

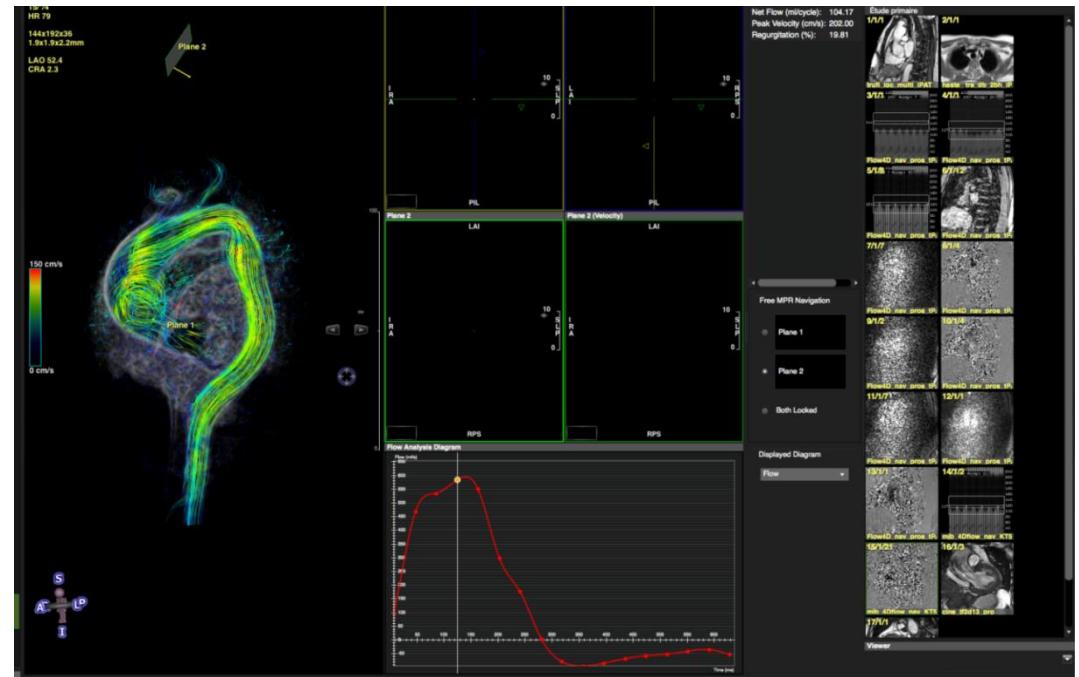


Streamlines, velocity

# Material and Methods- 4D MRI images

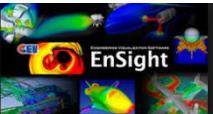
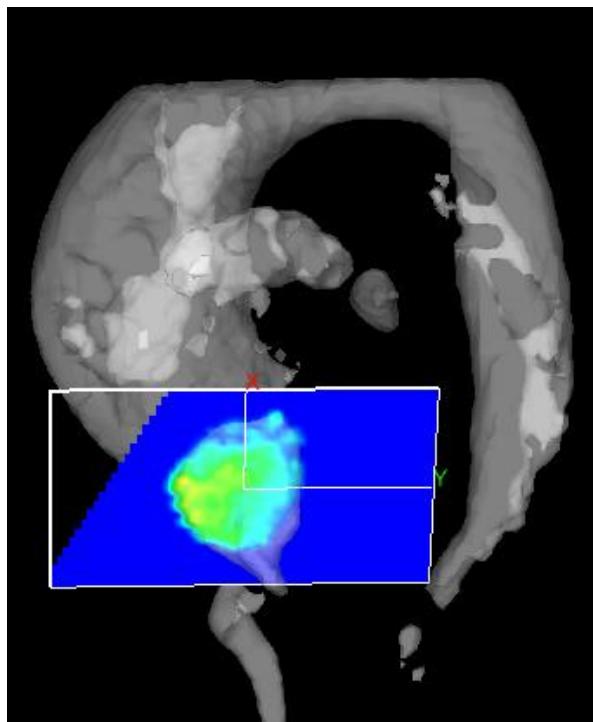


Siemens 3T Prisma



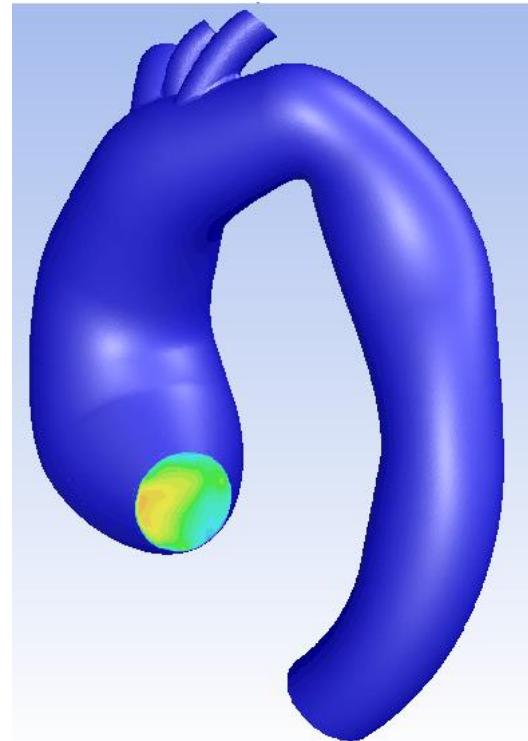
# MATERIAL AND METHODS- FSI

4D MRI data Velocity  
Profile



[17 m/s]

ANSYS<sup>®</sup>  
FLUENT<sup>®</sup>



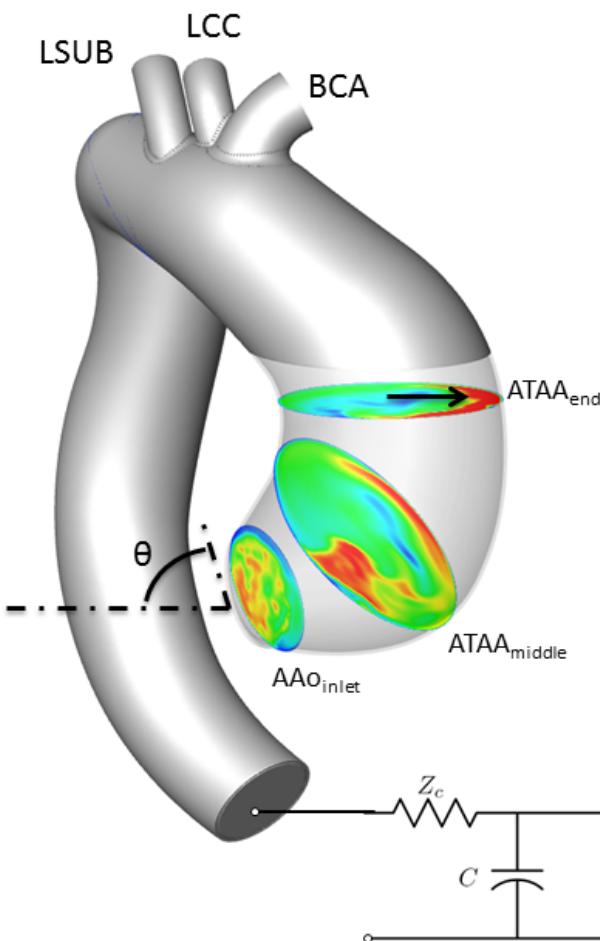
Condemi et al, ABME 2017

avril@emse.fr

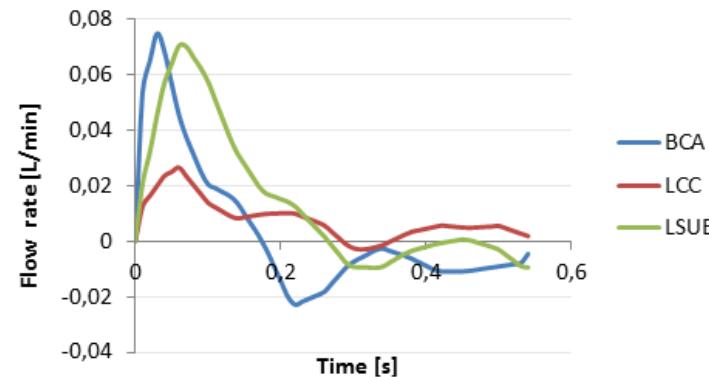
Stéphane Avril - 2018 Dec 19 - ISBM Nanjing

# Boundary conditions for the fluid domain

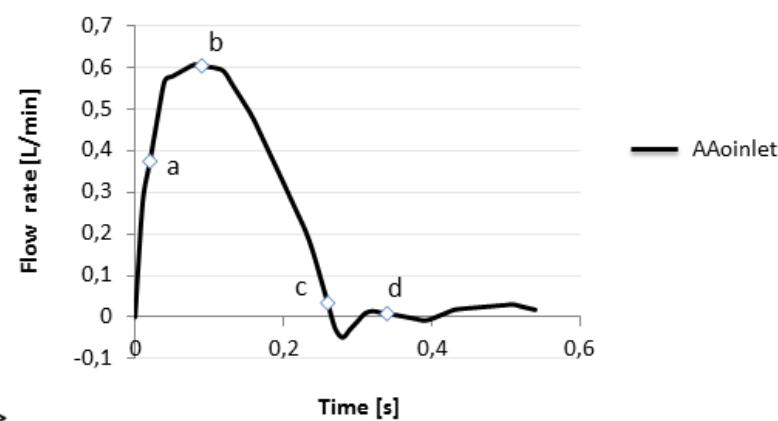
A



B

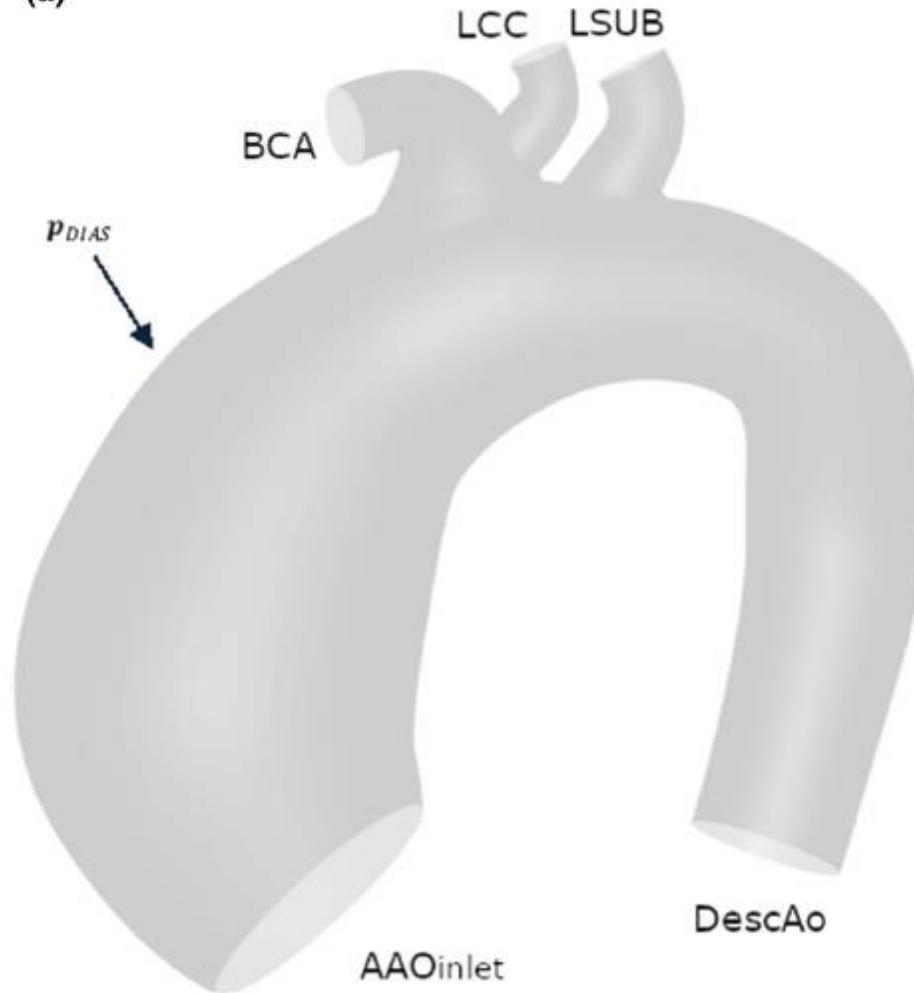


C

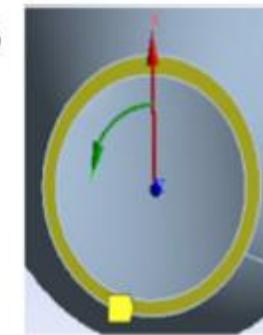


# Boundary conditions for the solid domain

(a)

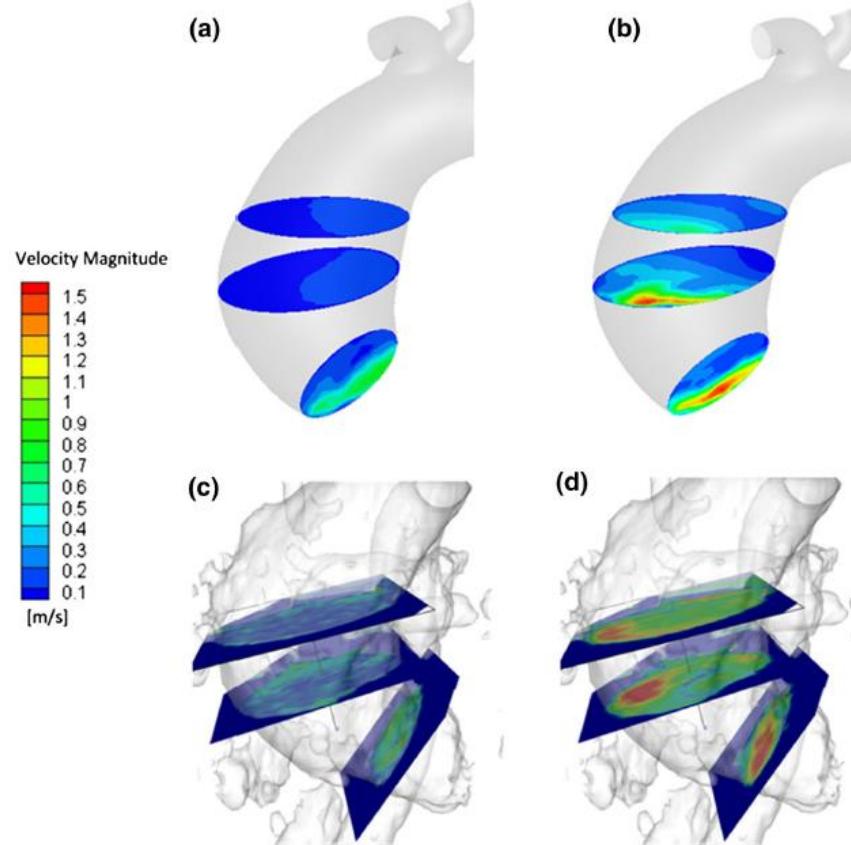
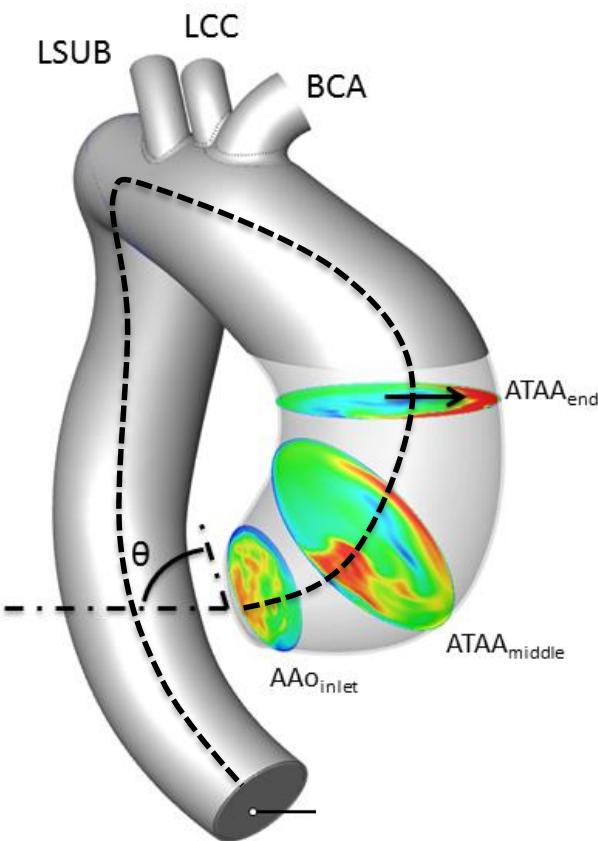


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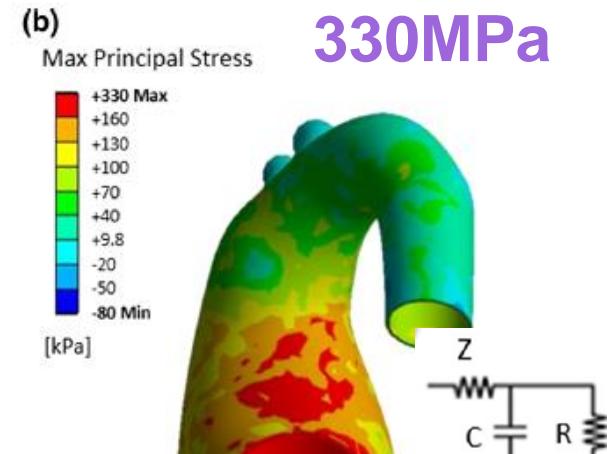
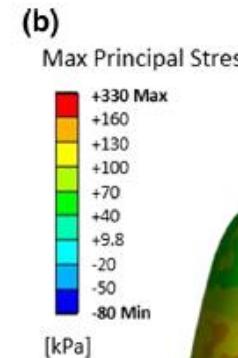
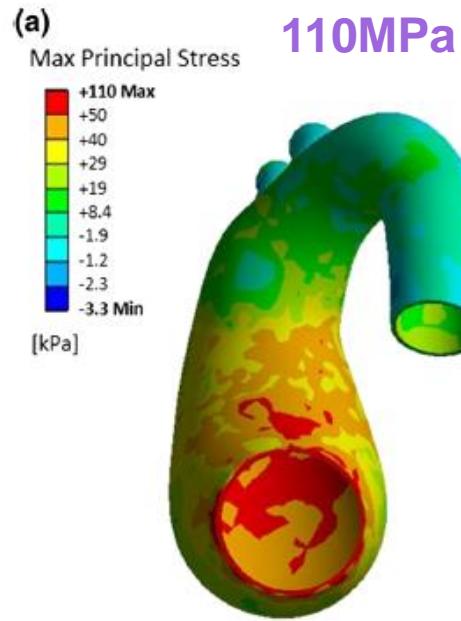
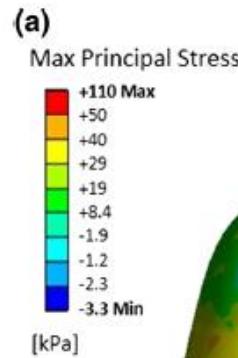


	x	y	z
AAO <sub>inlet</sub>	Free	Fixed	Fixed
DescAo	Free	Fixed	Fixed
Bca LCC Lsub	Fixed	Fixed	Fixed

# Validation of the computational model

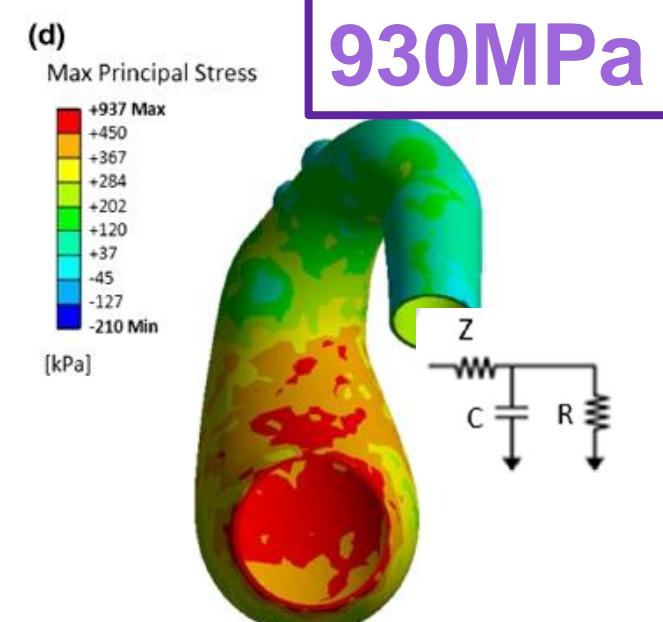
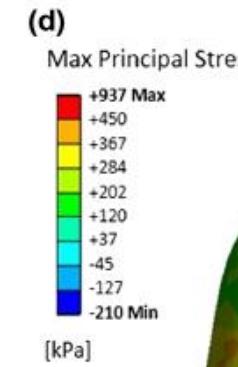
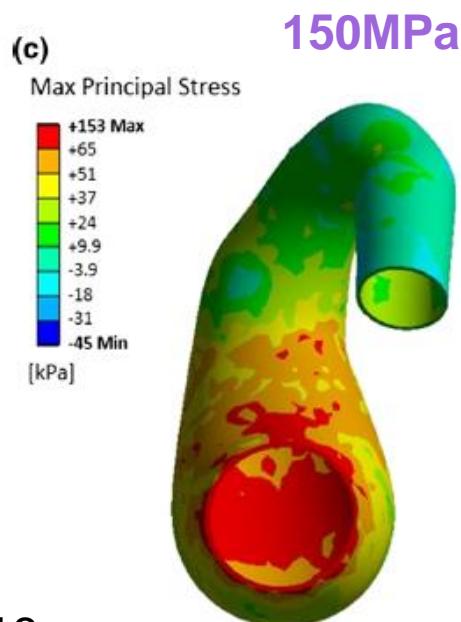
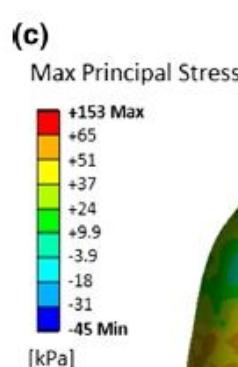


Sigovan, M., M.D. Hope, P. Dyverfeldt, D. Saloner. Comparison of four-dimensional flow parameters for quantification of flow eccentricity in the ascending aorta. J Magn Reson Imaging. 34(5):1226-30, 2011.



COMPLIANT

STIFF



# Wall shear stress analysis

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.

# RESULTS

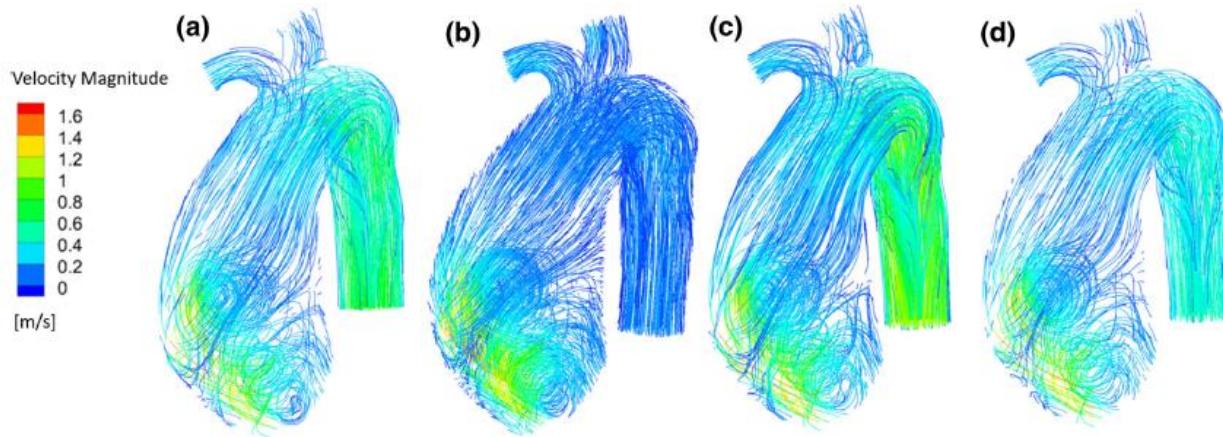
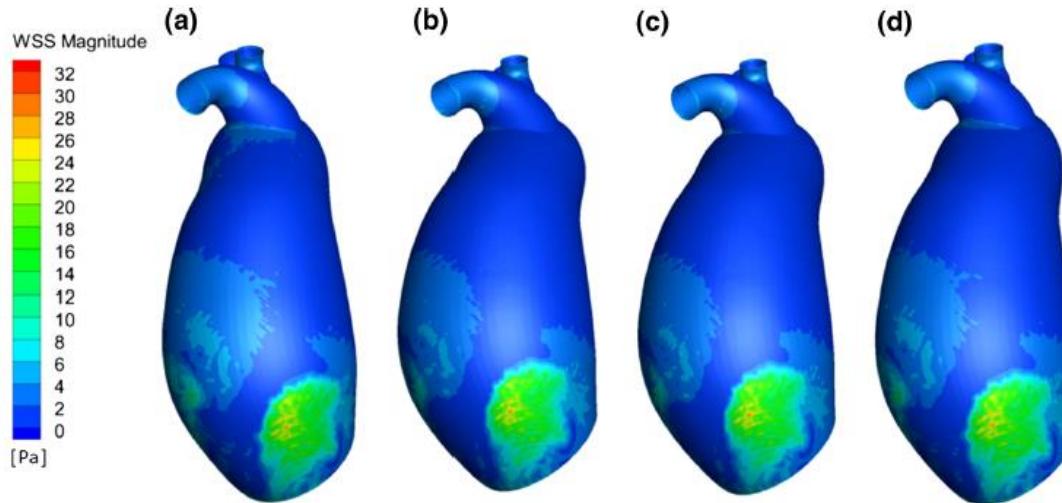
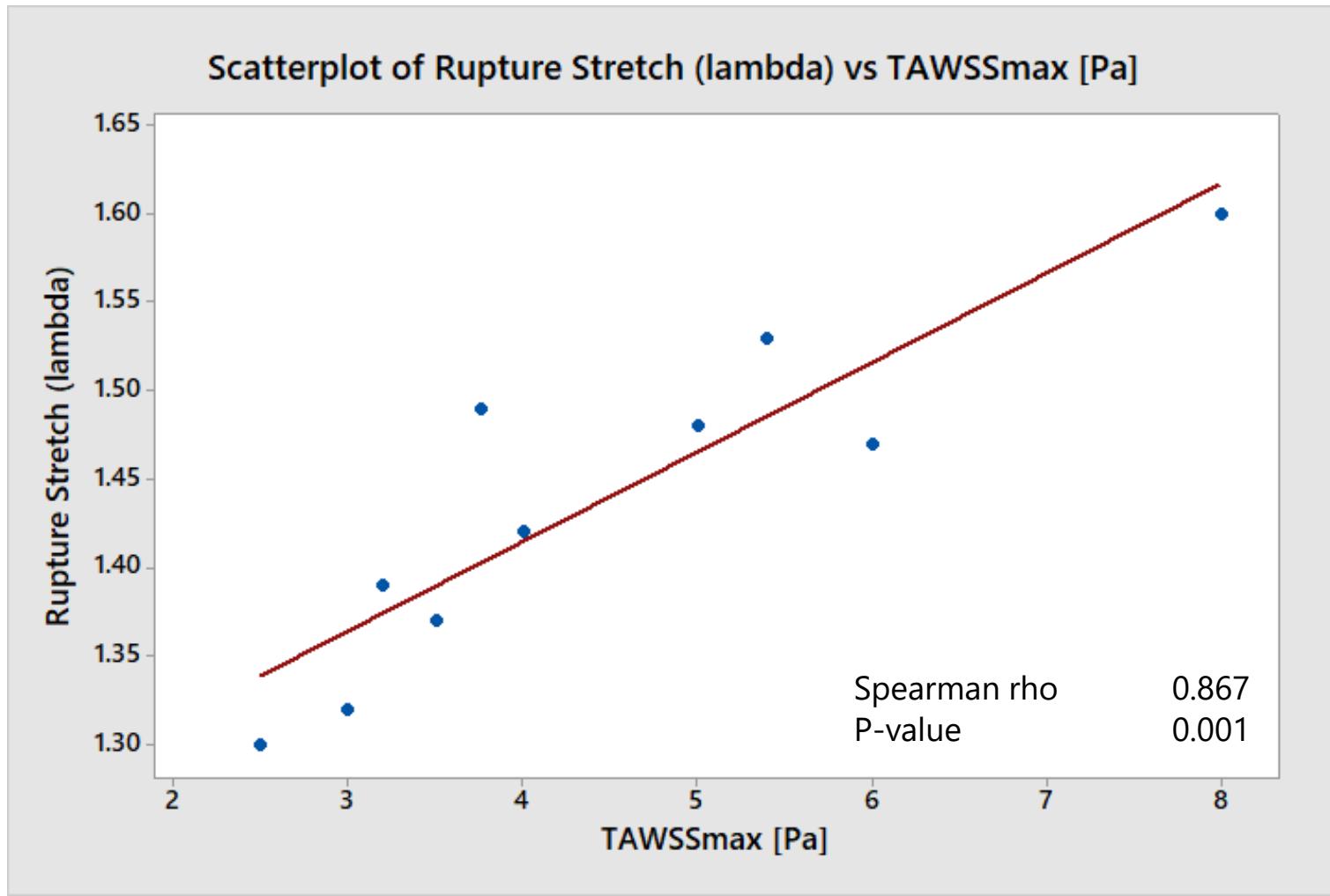


FIGURE 4. Streamlines of velocity simulated for case 1 (a), case 2 (b), case 3 (c) and case 4 (d). A jet flow impingement on the anterior region of the ascending aorta was found for all cases.

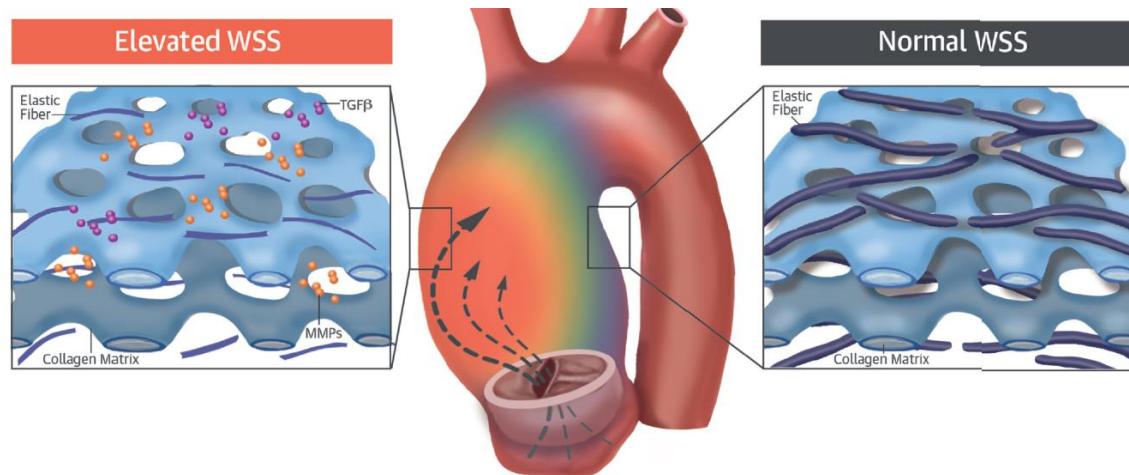


# Statistical Analysis-Spearman Rho: $\lambda_{\text{rupture}}$ vs. TAWSSmax [Pa]



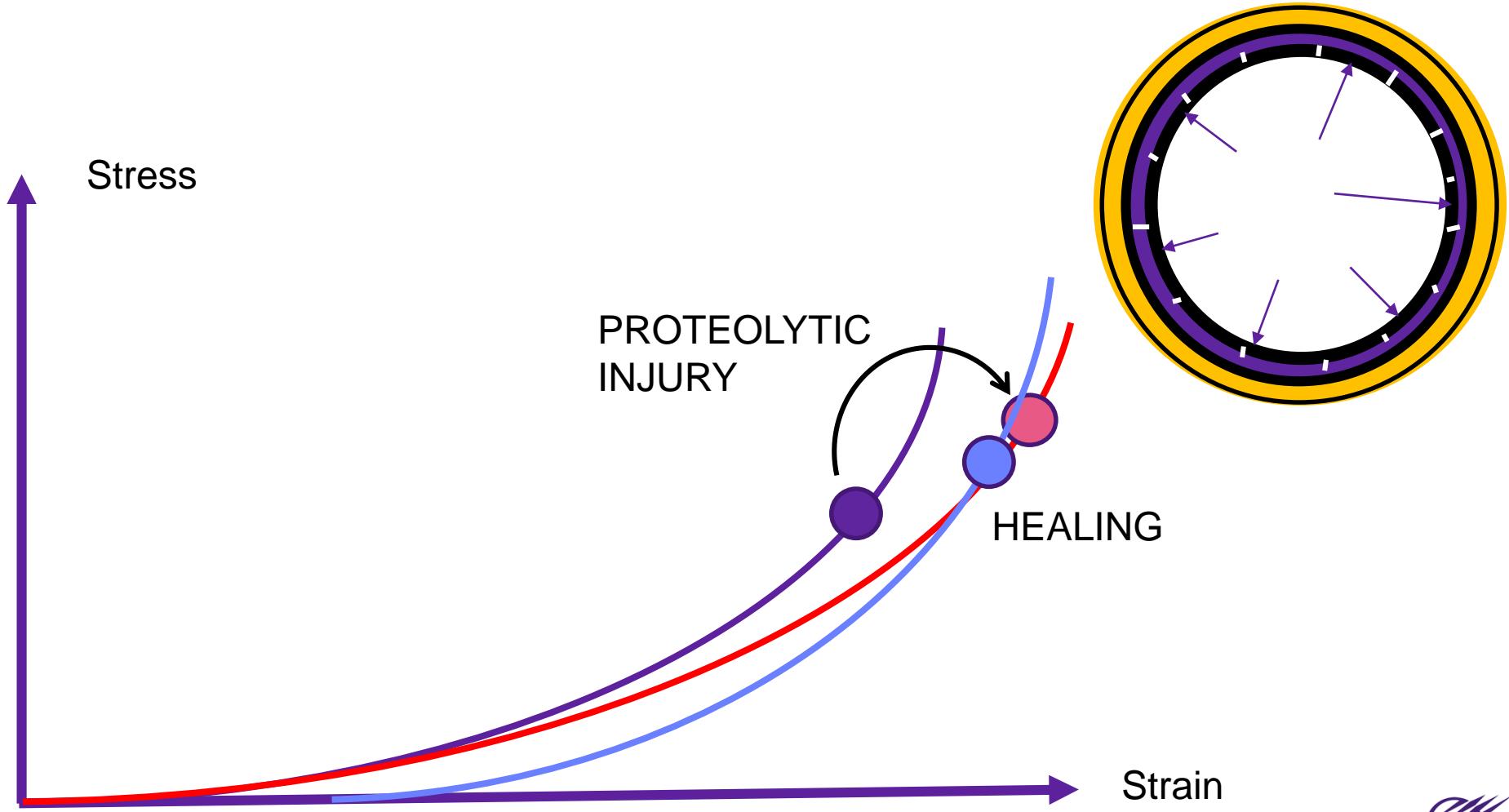
# DISCUSSION

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

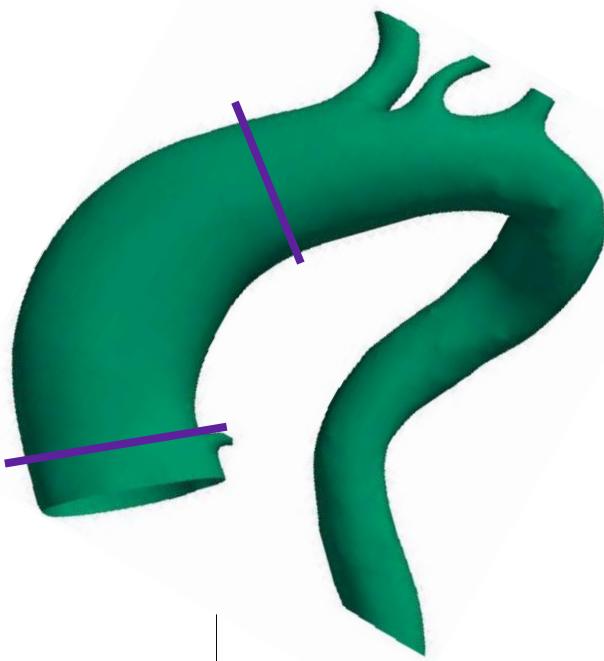


Guzzardi et al. JACC 2015

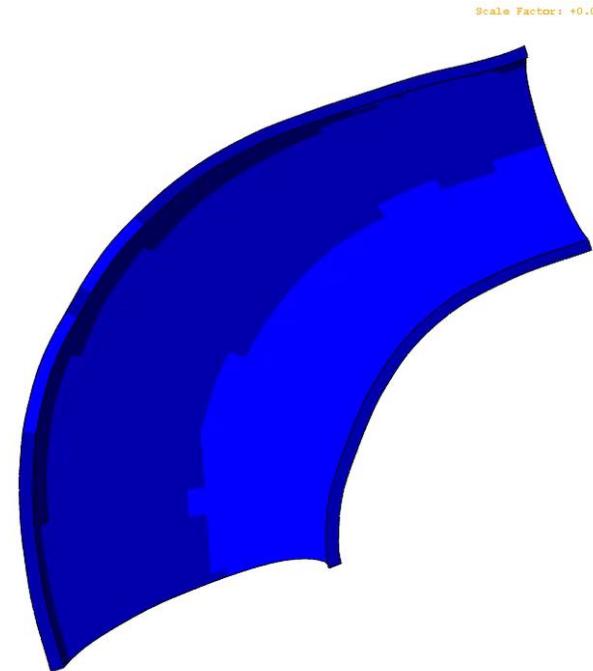
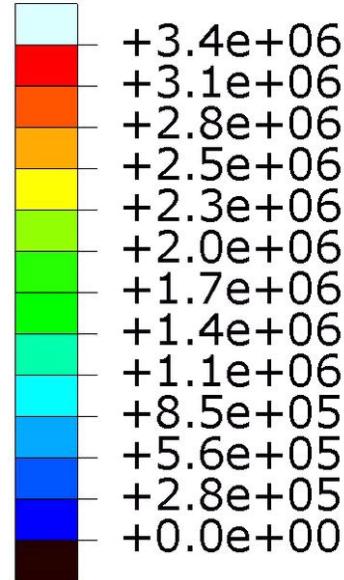
# Continuous process of proteolytic injury and tissue adaptation



# Growth and remodeling with continuous medial proteolytic injury



S, Max. Principal  
(Avg: 75%)

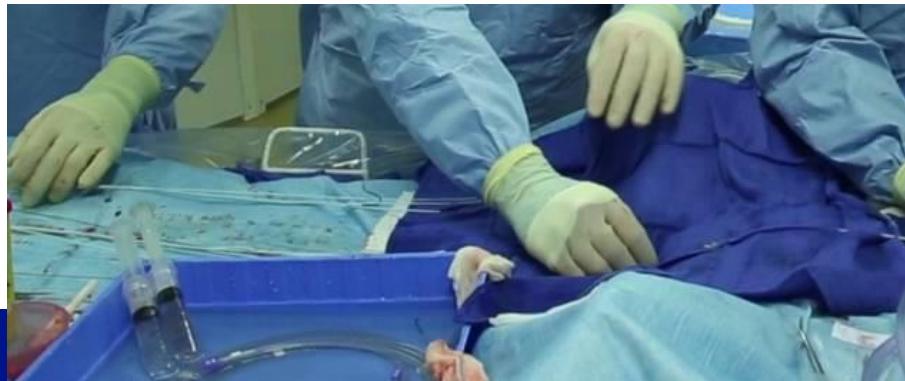


Mousavi et al, BMMB 2018



# Computational mechanics in the OR for vascular surgery?

[www.predisurge.com](http://www.predisurge.com)



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