Soft tissue biomechanics and its challenges for experimental mechanics

Focus on blood vessels

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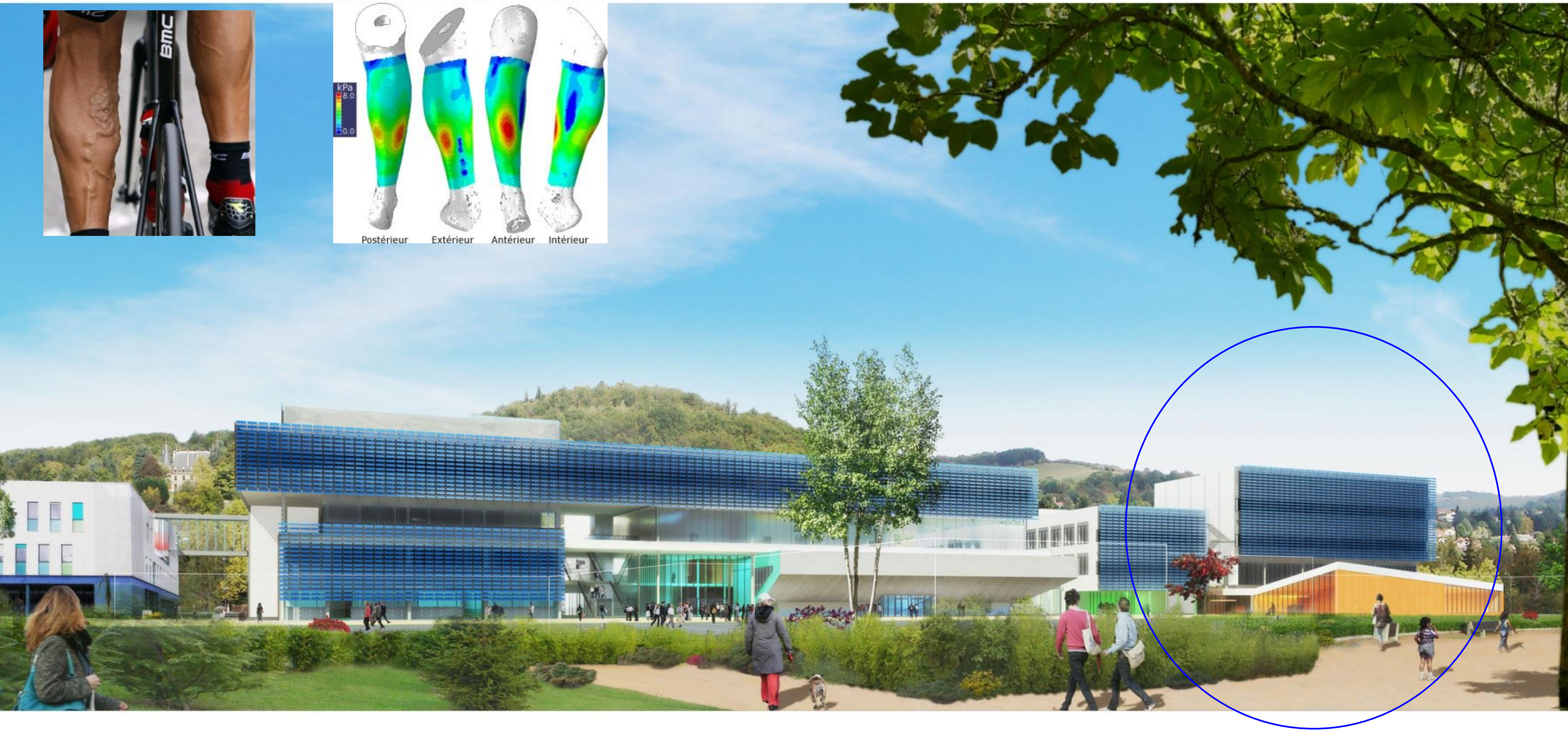
Historical site

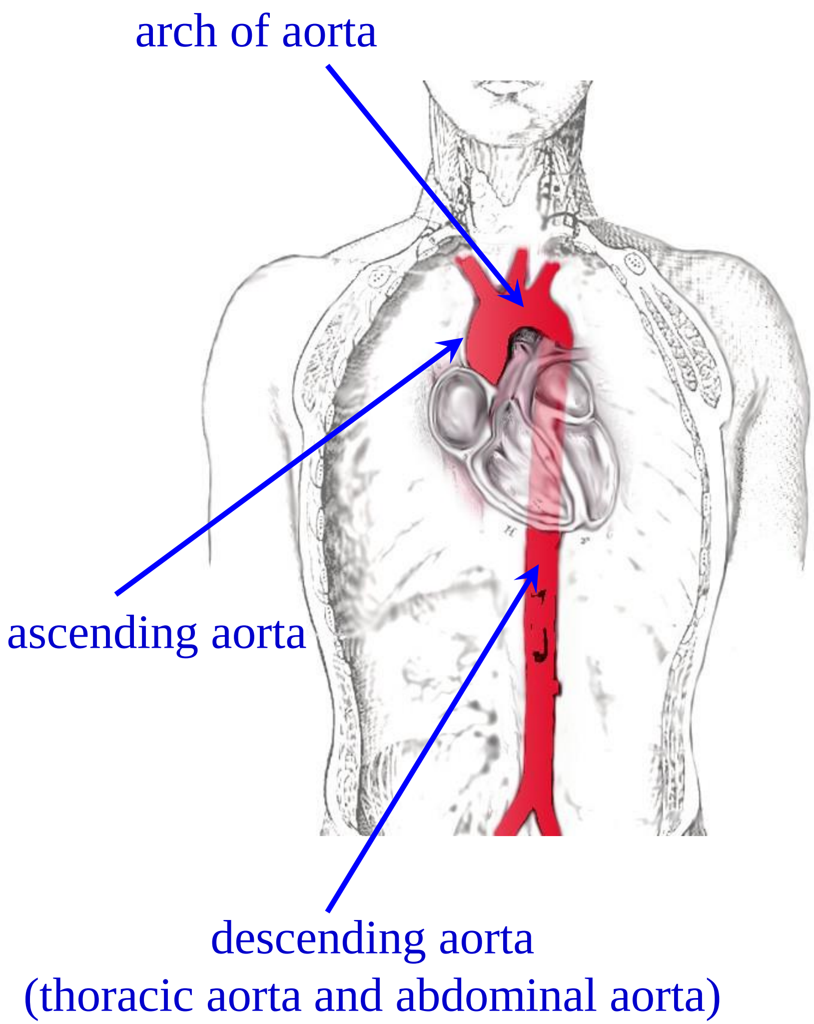
Founded in 1816

Center for Biomedical and Healthcare Engineering
CIS - Centre Ingénierie et Santé

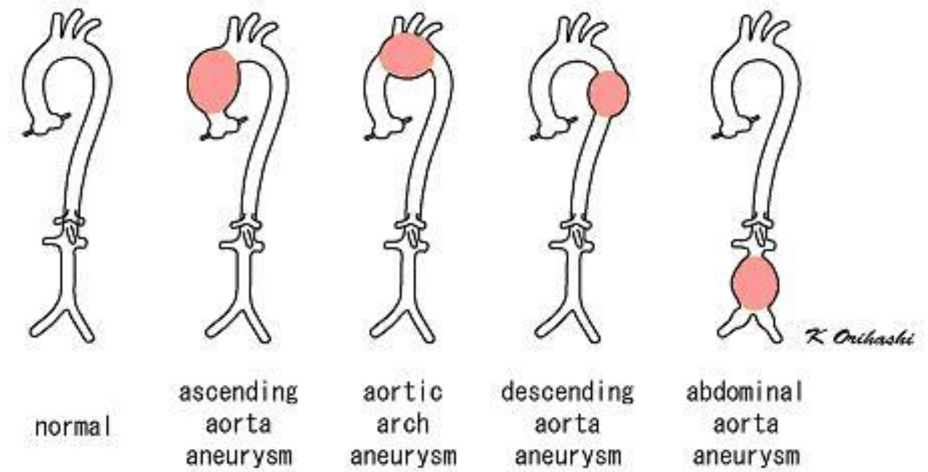


Campus with hospital, medical school, prevention center, college of engineering and companies manufacturing medical devices

FOCUS ON AORTIC ANEURISMS



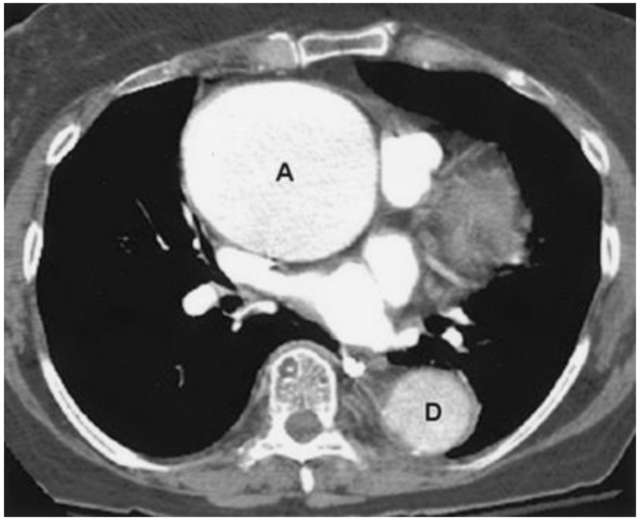
- a local dilation of the aorta due to aortic wall weakening

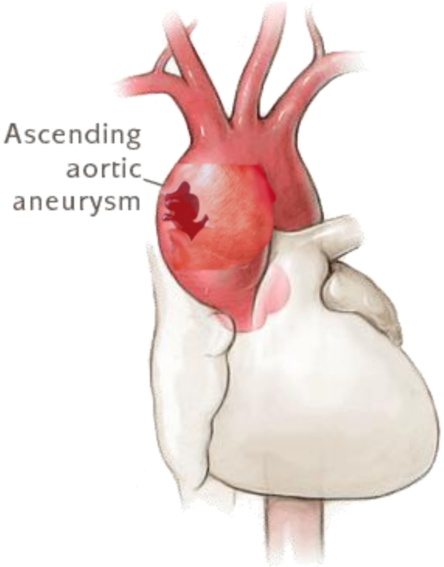


Various aortic aneurysms

SOCIETAL AND MEDICAL ISSUES

Thoracic aortic aneurysms per year: 15000 people in the US, +30000 people in Europe with a male preponderance. 50-60% involves the ascending aorta.

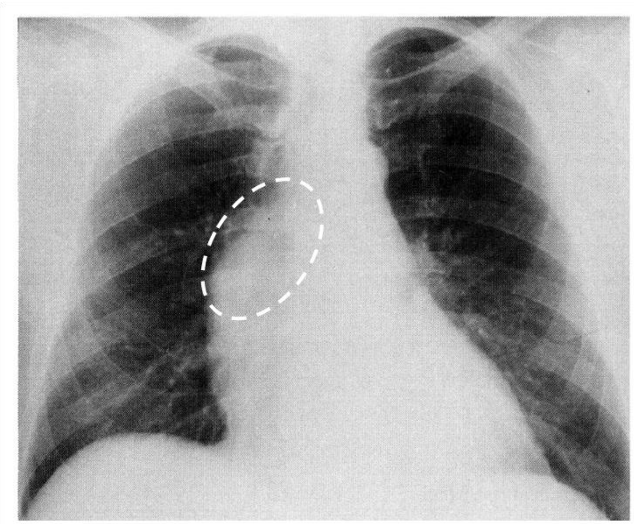




How can we predict the aneurysm's rupture?

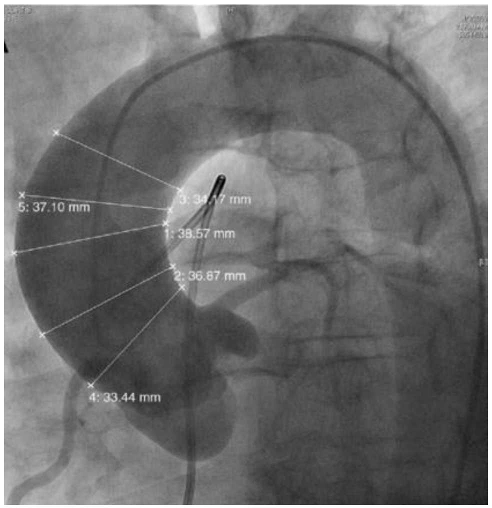
MEDICAL QUESTIONS

(Sullivan et al., 1988; Evangelista, 2010; Elefteriades et al., 2010)



X-ray

MRI



Aortogram

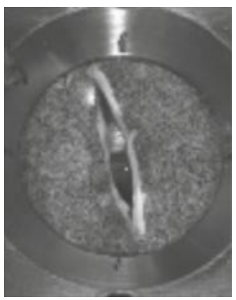
- Spontaneous detection
- Morphological measurements
- **Diameter criterion (>55 mm)**

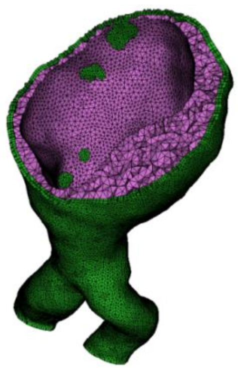
"Small aneurysms can also rupture"
(Nicholls et al., 1998)

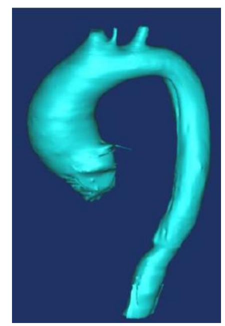
"Bigger aneurysms may never rupture"
(Elefteriades et al., 2010)

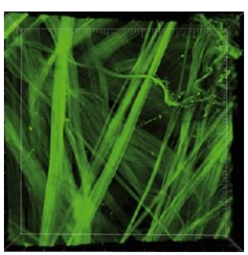
Soft tissue biomechanics at CIS

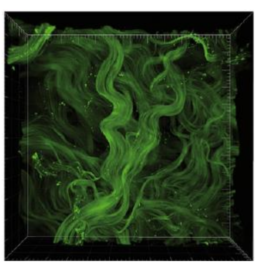
Our vision is to establish biomechanical models to predictively design therapies of cardiovascular diseases adapted to each patient





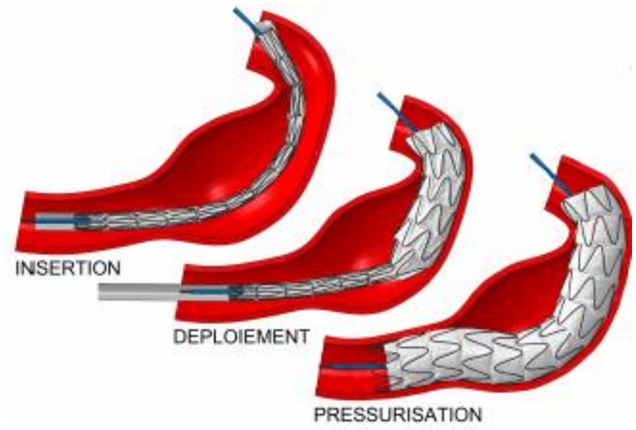


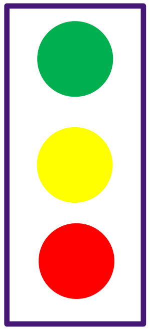




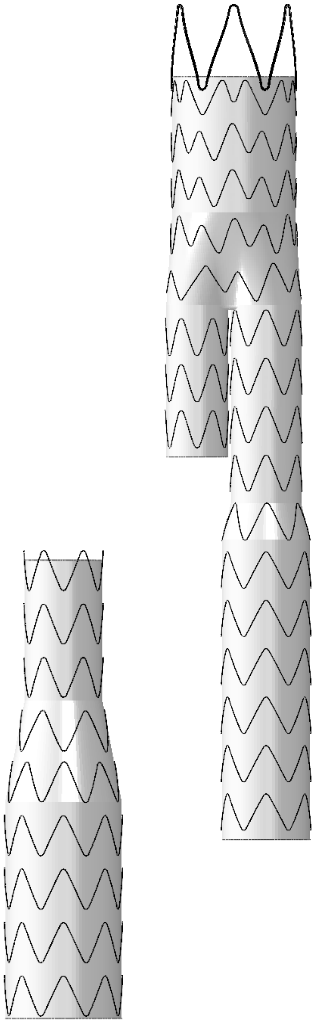
EXAMPLE

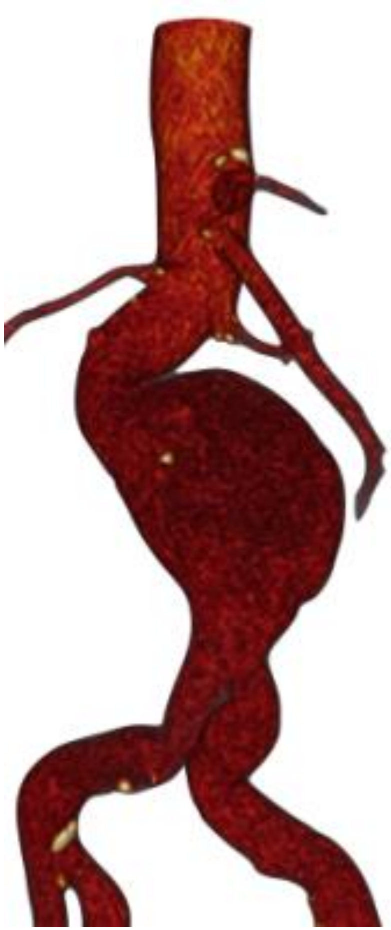
Predictive planning software solution for endovascular surgery


INSERTION
DEPLOIEMENT
PRESSURISATION



AAA and stent-graft modeling





Preoperative scanner

↓

Segmentation (Endosize)

↓

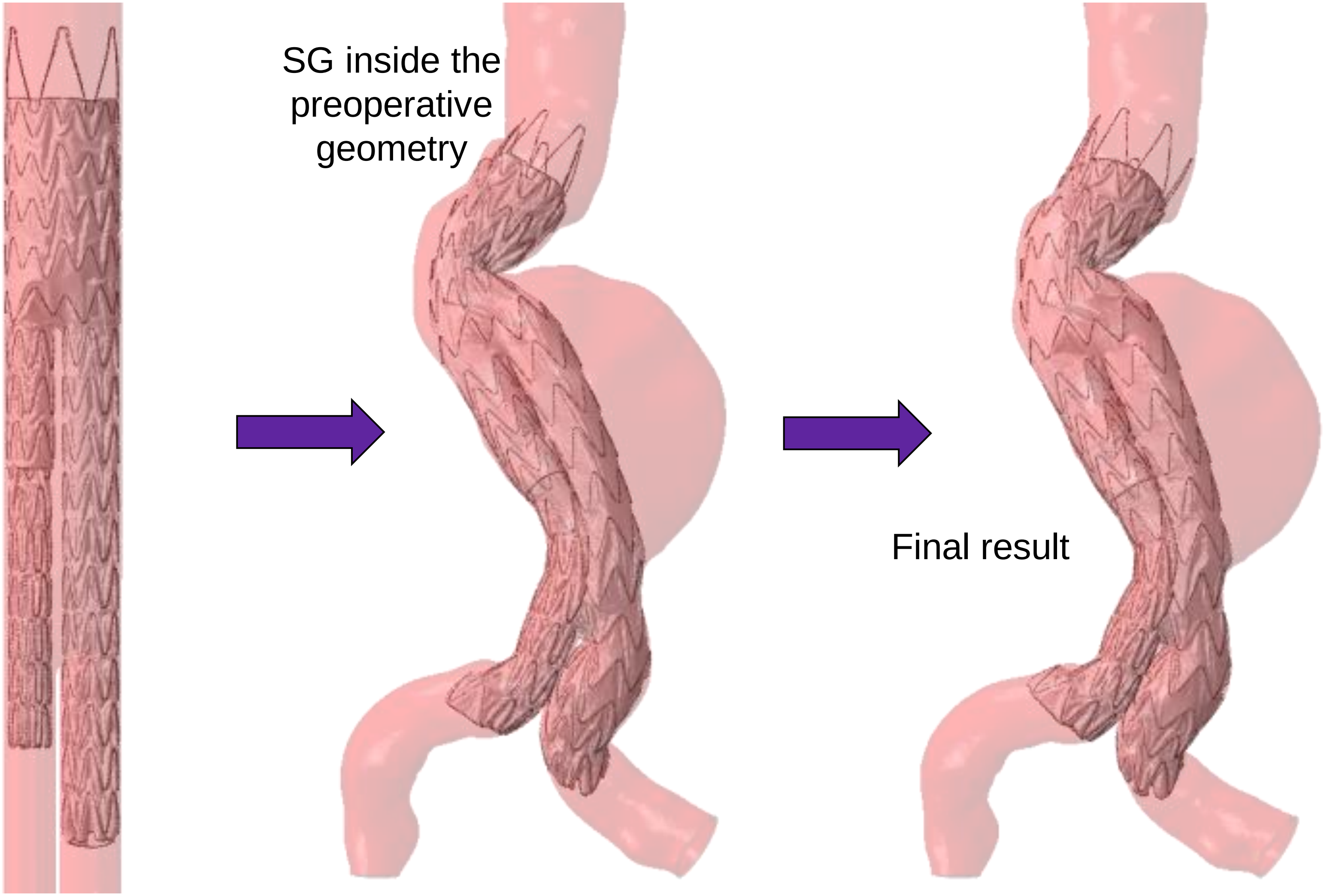
Meshing

+

AAA mechanical properties

SG deployment FE simulation

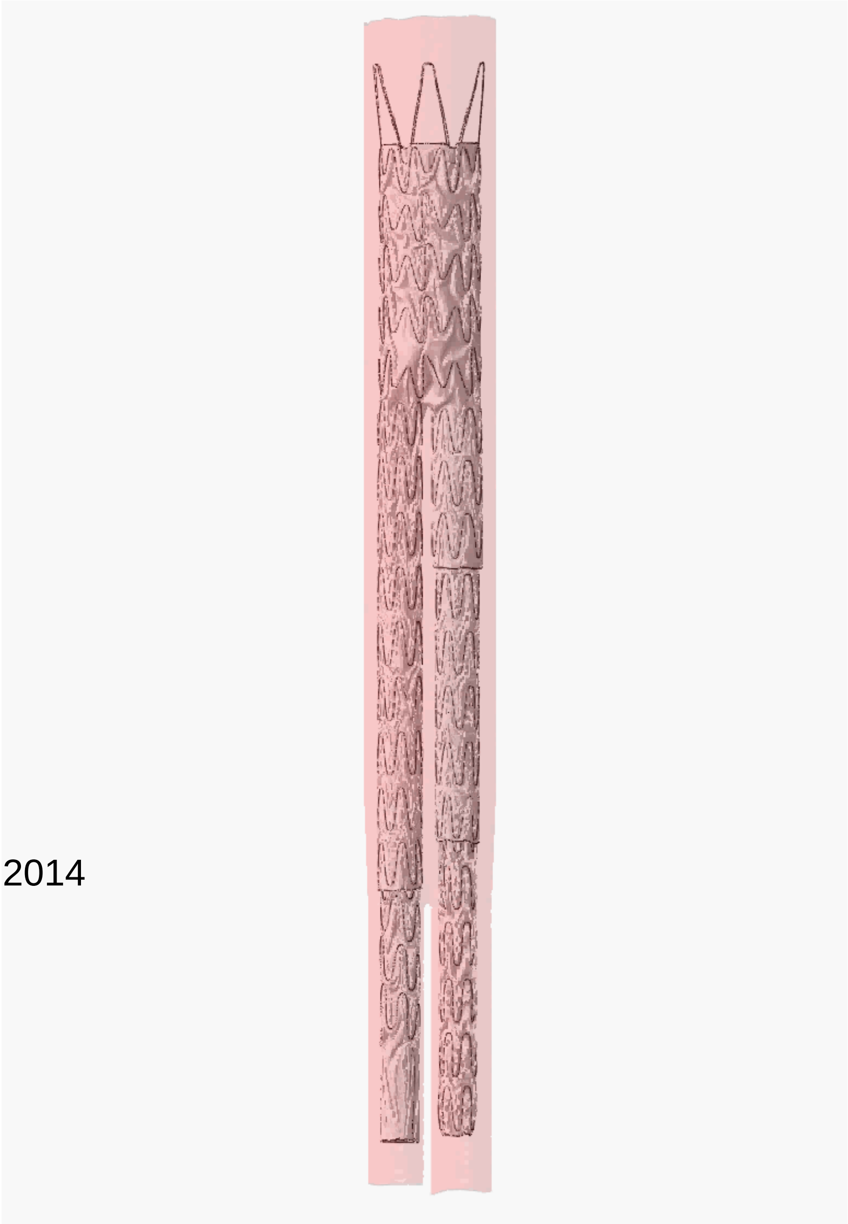
SG inserted inside a tubular shape



Vidéo

SG deployment FE simulation

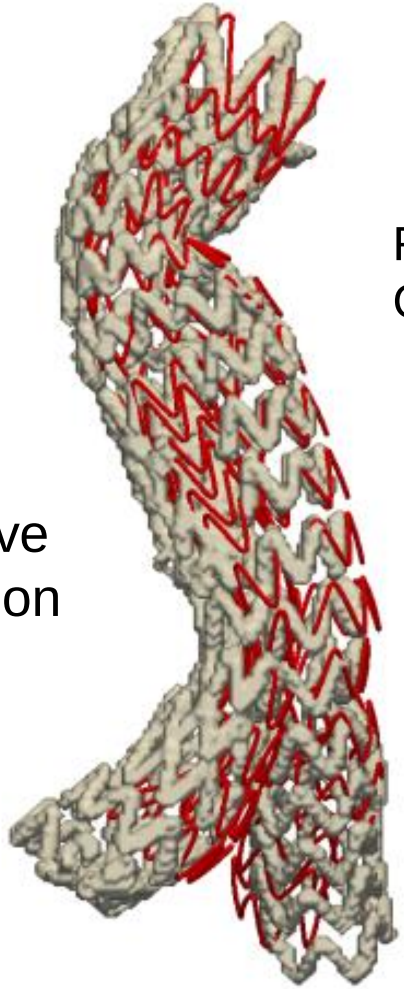
Perrin et al, Journal of Biomechanics 2014



Comparison with the postoperative scanner

Postoperative scanner

Qualitative comparison



Red: simulation
Grey: scanner

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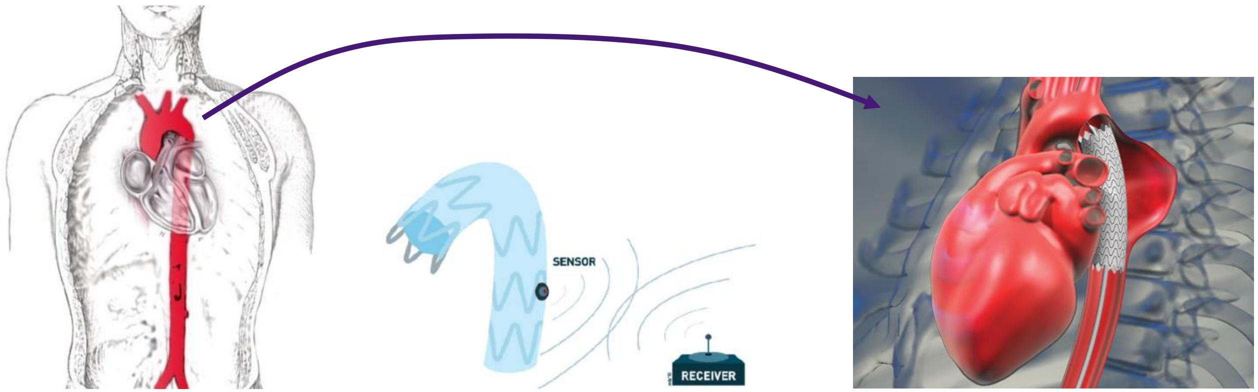
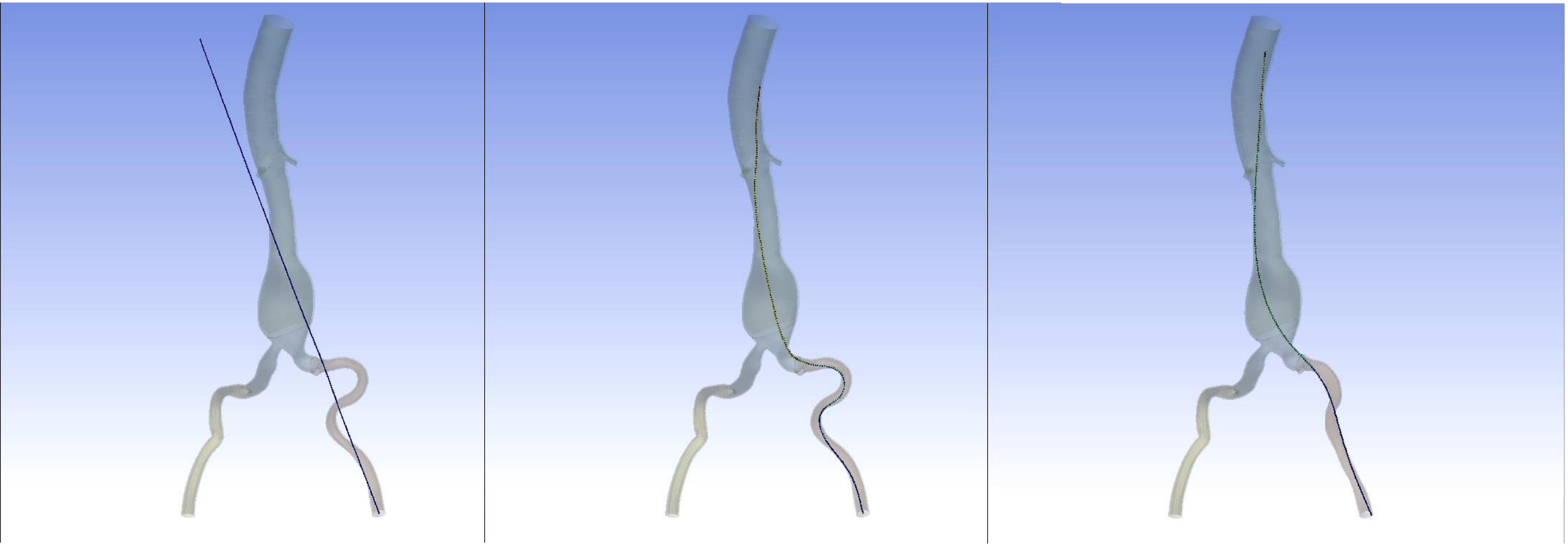
1st CHALLENGE

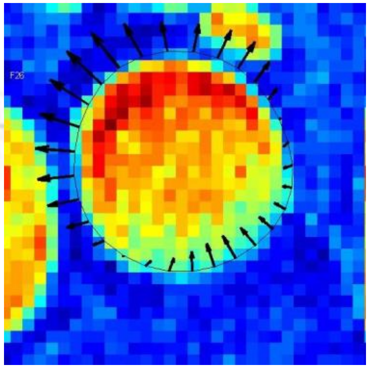
Selection of patients for a treatment

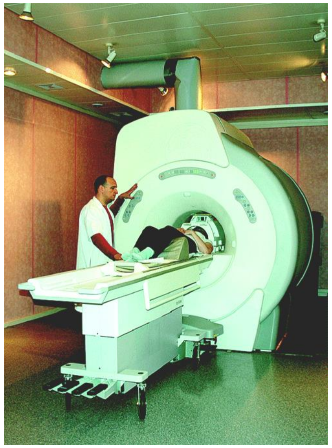


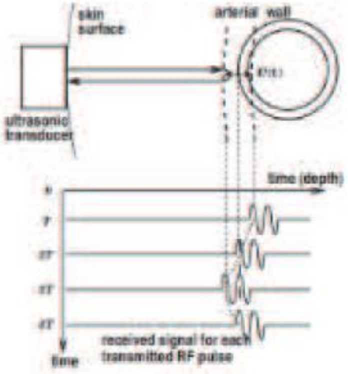
INTRODUCTION



ELASTOGRAPHY OF ARTERIES IN VIVO: different techniques based on medical imaging



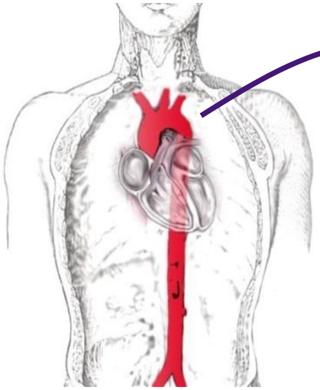


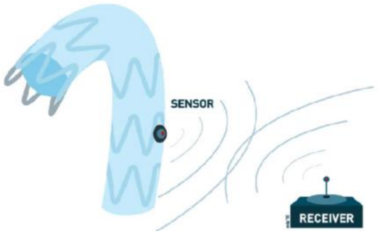


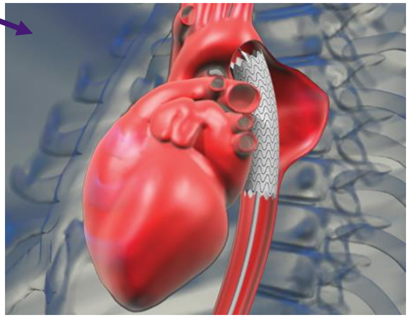
Kanai et al. 2003, Couade et al. 2010, Masson et al. 2006

2nd CHALLENGE

Predictive planning of the treatment







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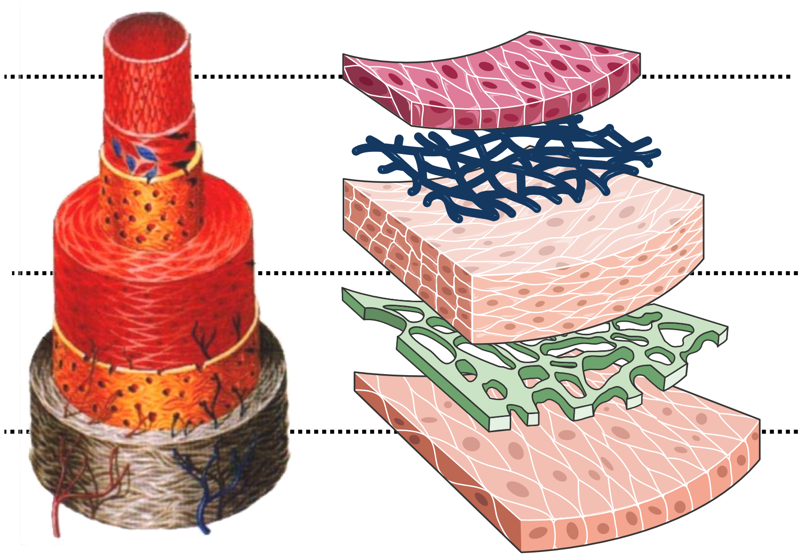
Methodology

- **Understanding of the regulatory mechanisms involved in controlling collagen metabolism is fundamental to the predictive design of therapies**

- **Purpose of *experimental mechanobiology***

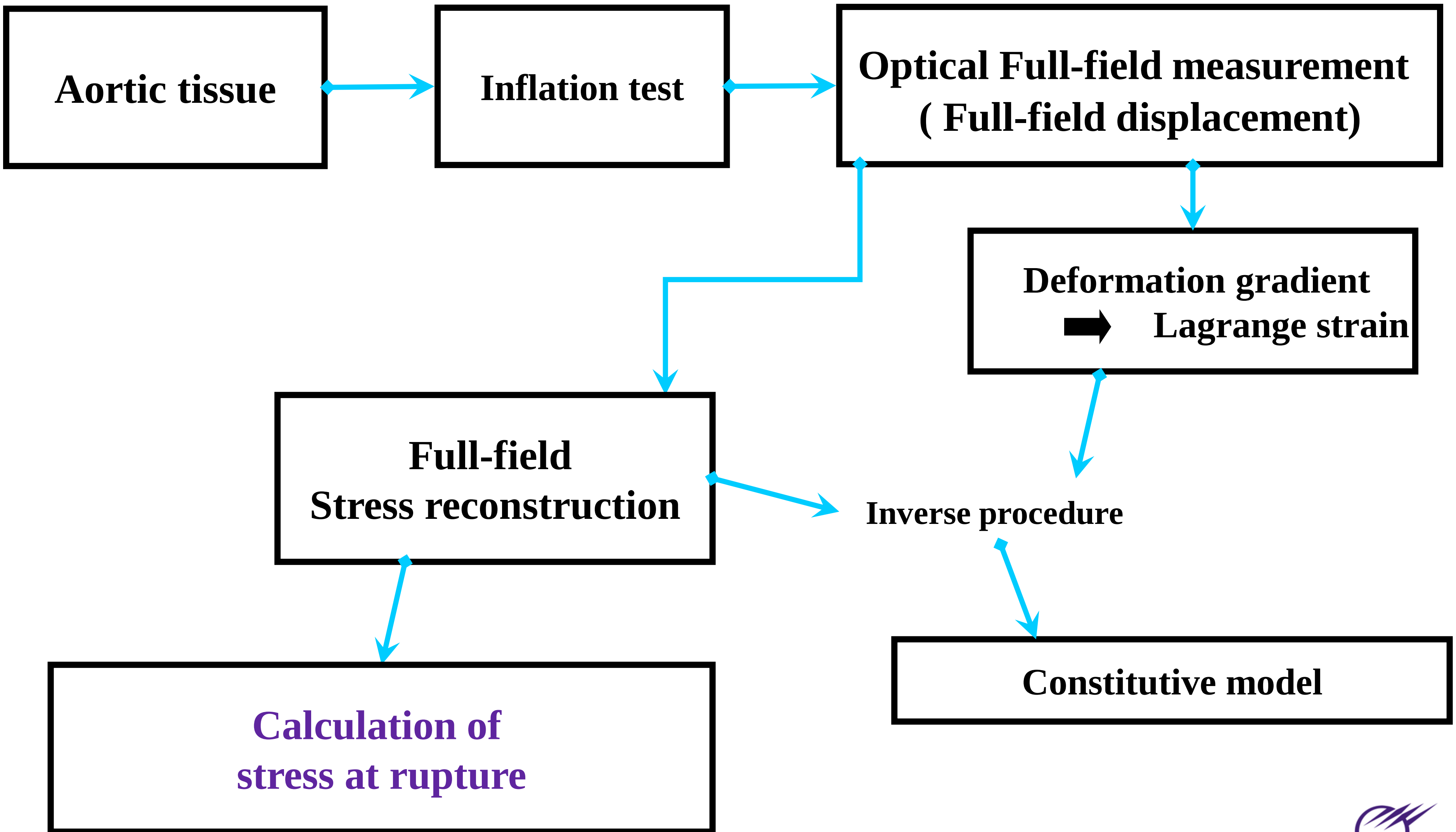


Intima — Biologic sensor and filter

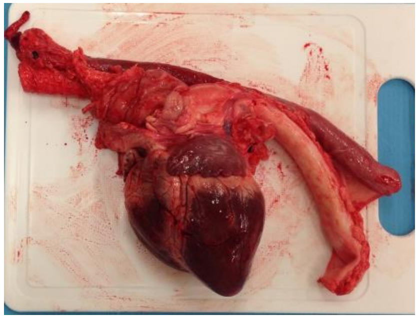
Media — Smooth muscle cells, **Elastin fibers**, **Collagen fibers**

Adventitia — **Collagen fibers**

Example of methodology

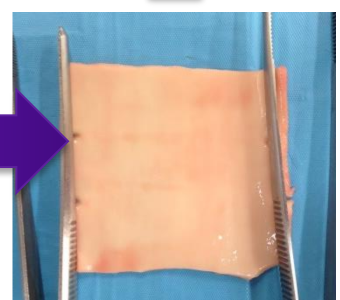


Experimental tests on animal tissues

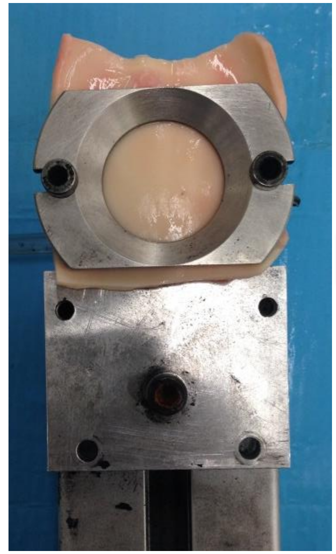


Isolation of aorta

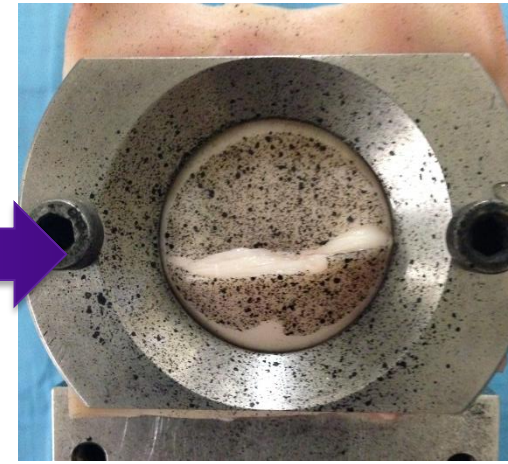
Axial cut along aorta



Cleaning of sample and
circumferential cut

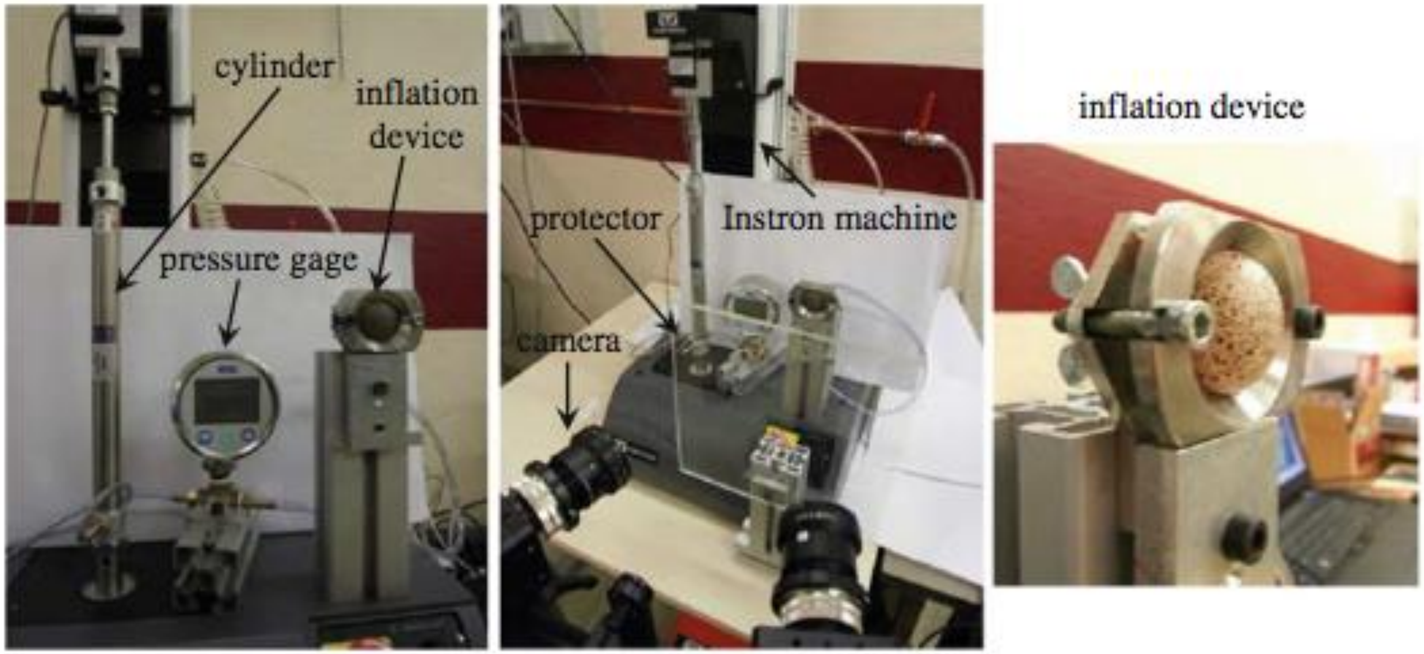


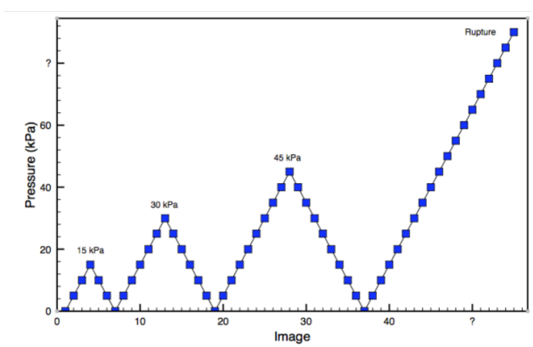
Place in testing apparatus



Apply speckle paint and
perform rupture test

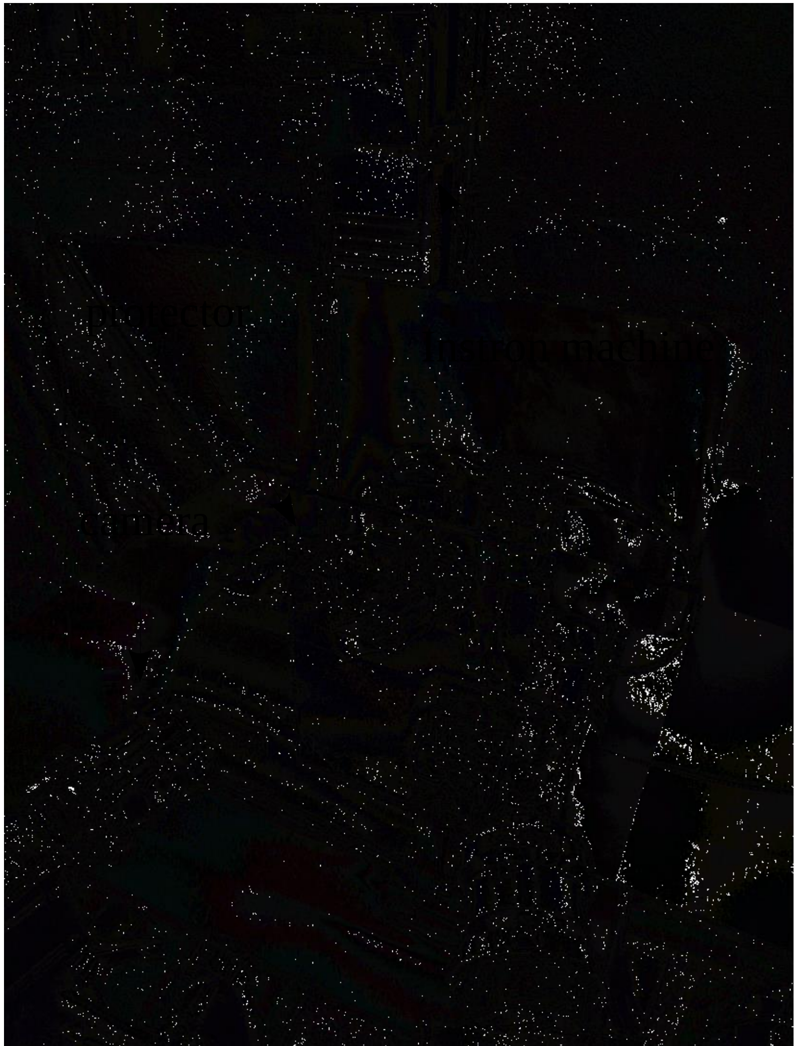
Experimental tests

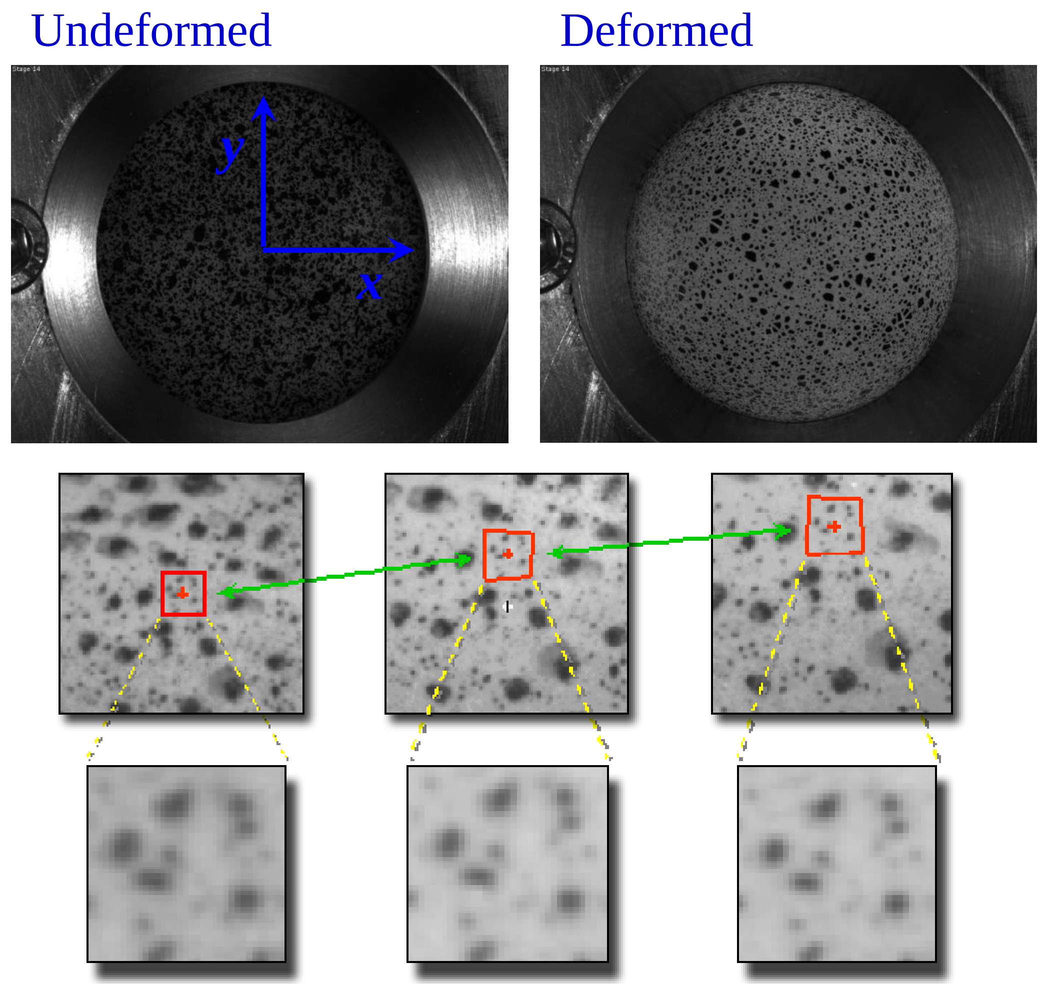




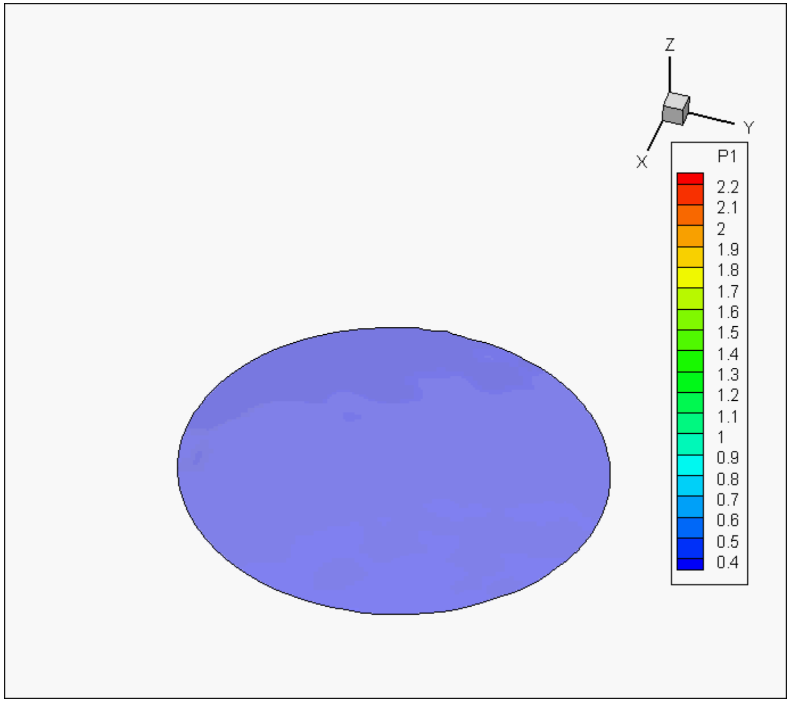
- Protocol:
  - Ramp to 15, 30, 45, rupture
  - Pump speed: 5 mL/min
  - Picture every 5 kPa

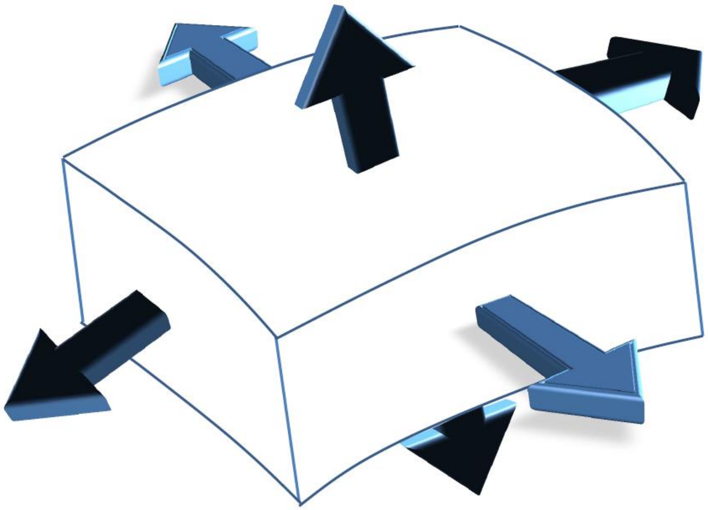
Full-field measurements





Local stress reconstruction



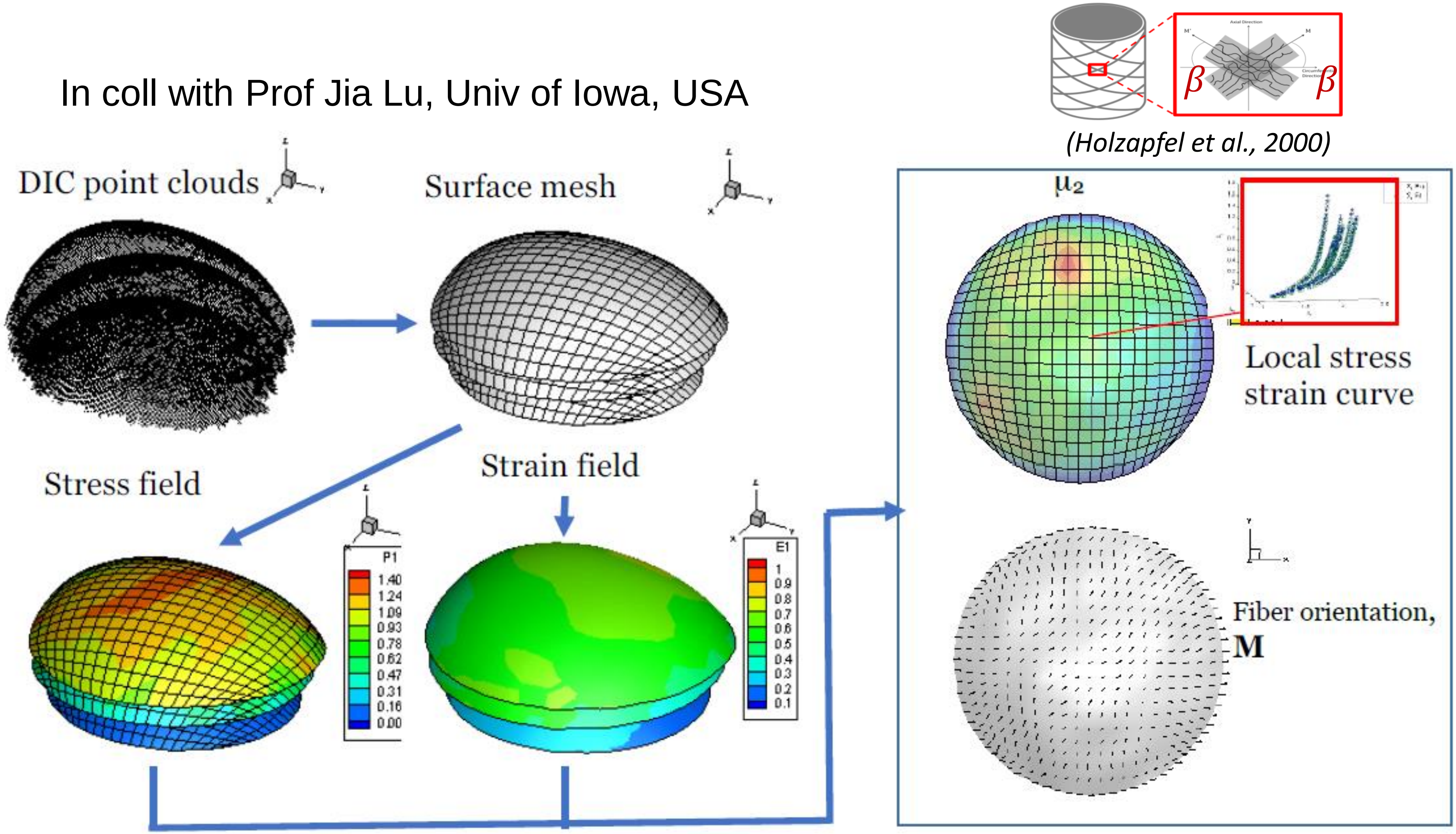


$$div(\boldsymbol{\sigma}) + f = 0$$

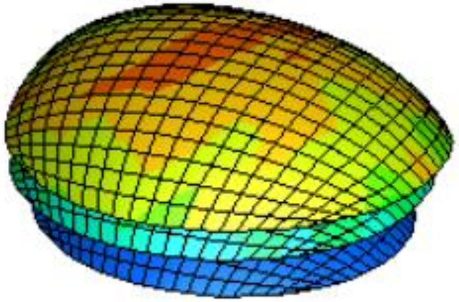
$$[A] \cdot [\boldsymbol{\sigma}] = [B]$$

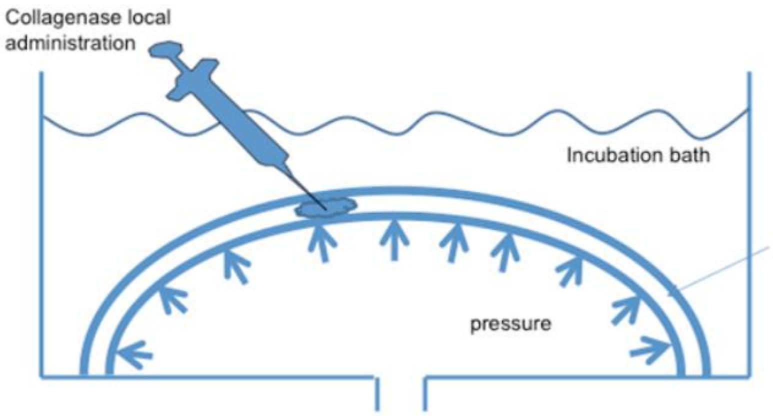
Full-field measurements and identification of a hyperelastic constitutive model

In coll with Prof Jia Lu, Univ of Iowa, USA

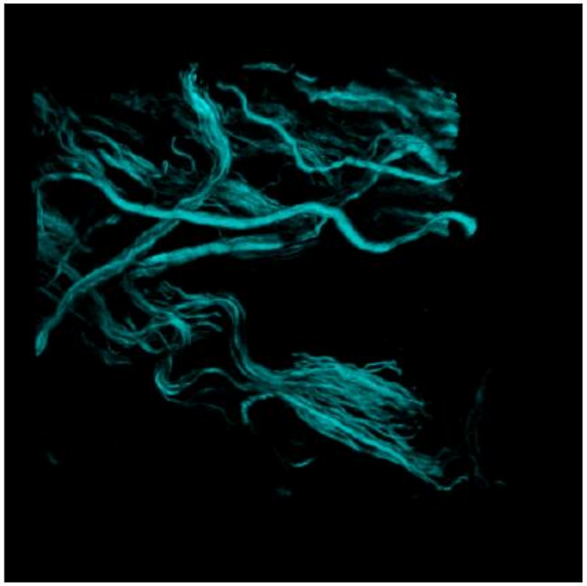


Characterization of the influence of collagen degradation onto the constitutive properties

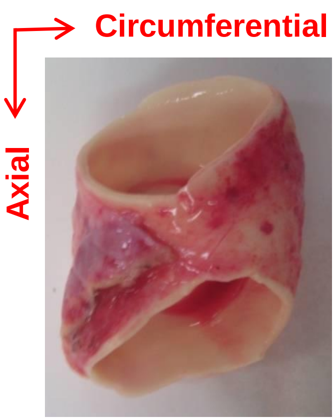




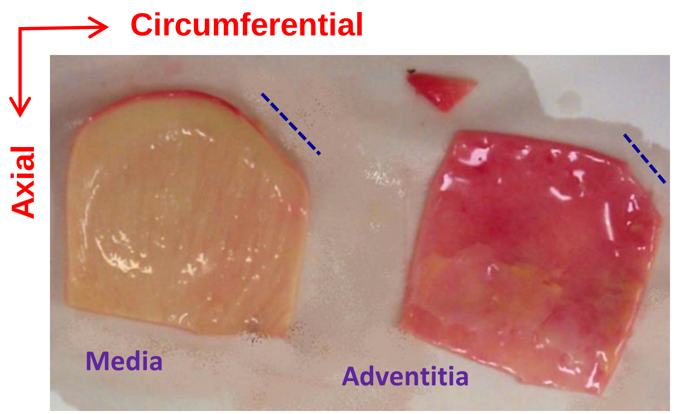
Combination with multiphoton microscopic imaging



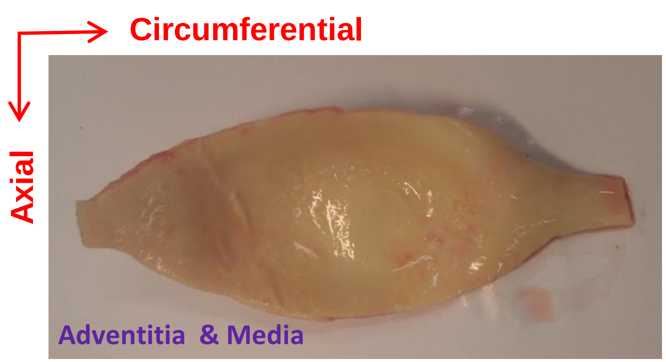
Application in a clinical protocol: modes of rupture of aneurisms of the ascending thoracic aorta



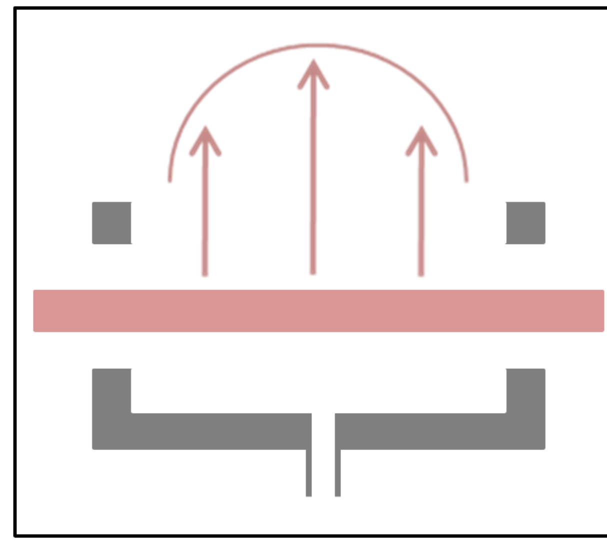
I) Aneurysm excised specimen.



II) Separation of Media and Adventitia.

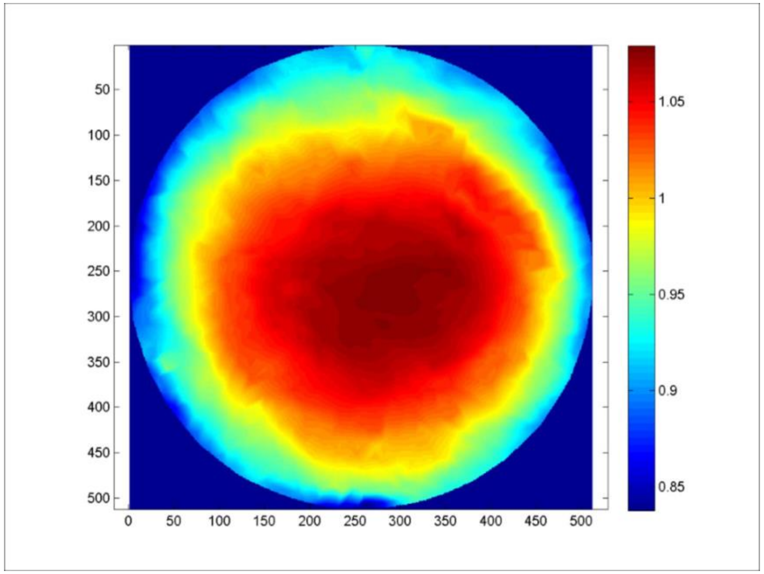


II) Media and Adventitia.

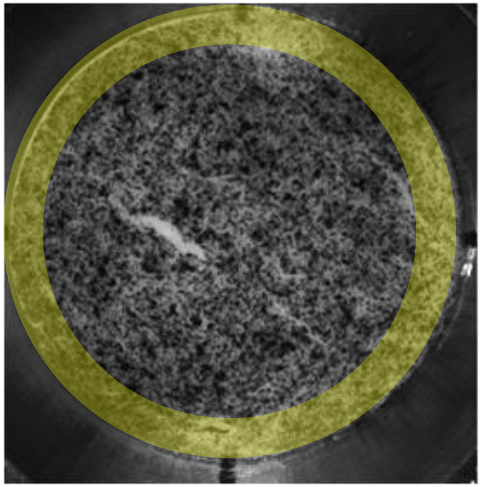


Local analysis of rupture

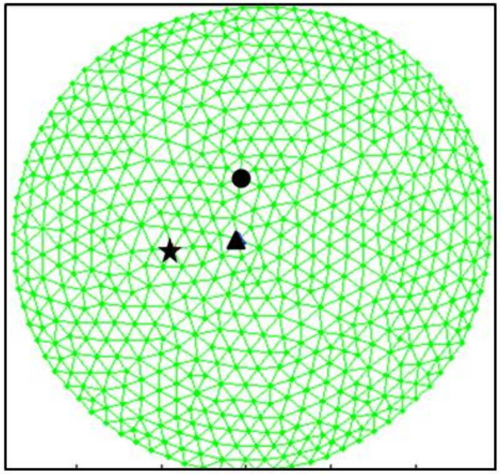
Local thickness evolution (mm)



Rupture picture and area of interest



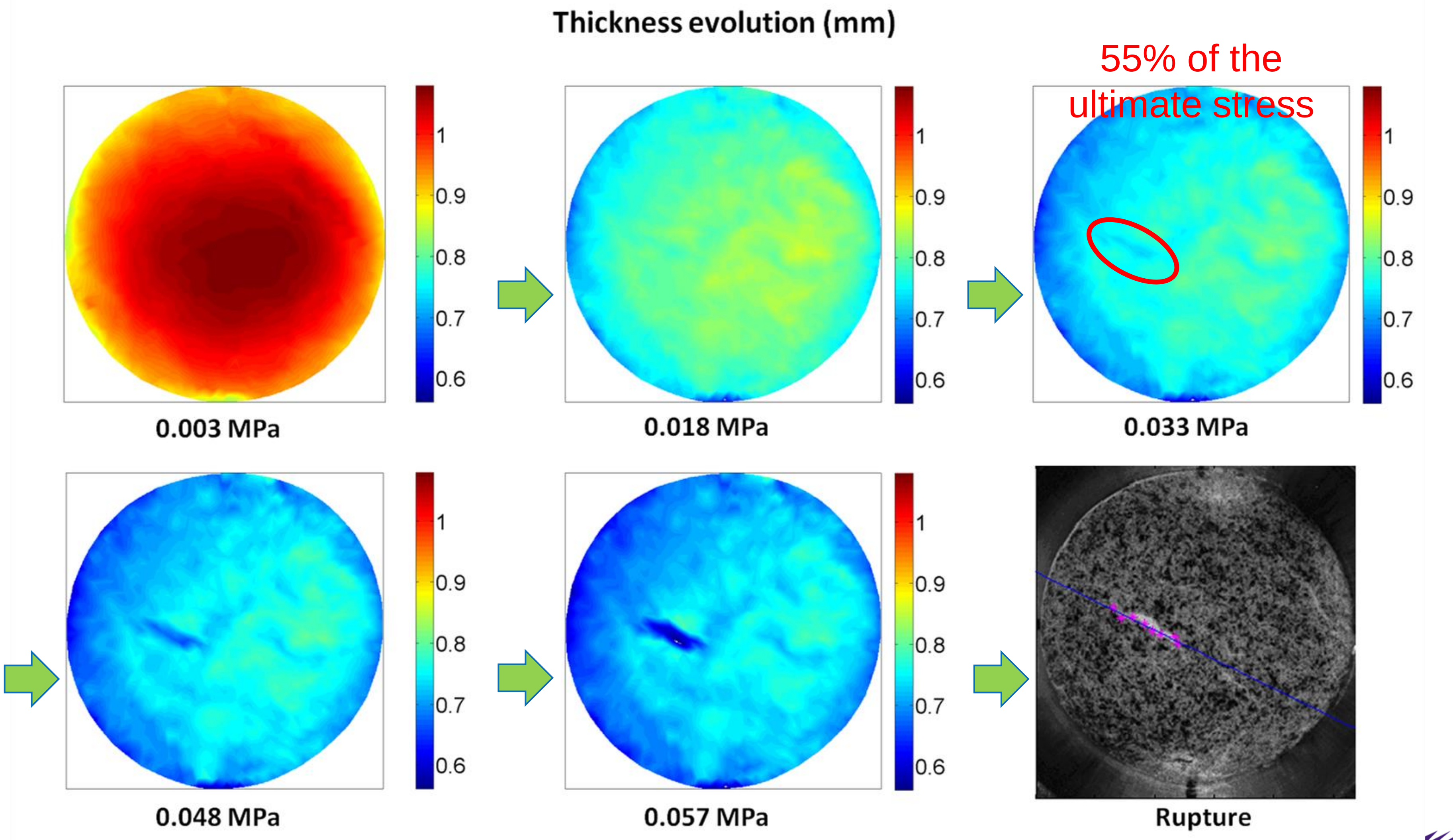
Mesh



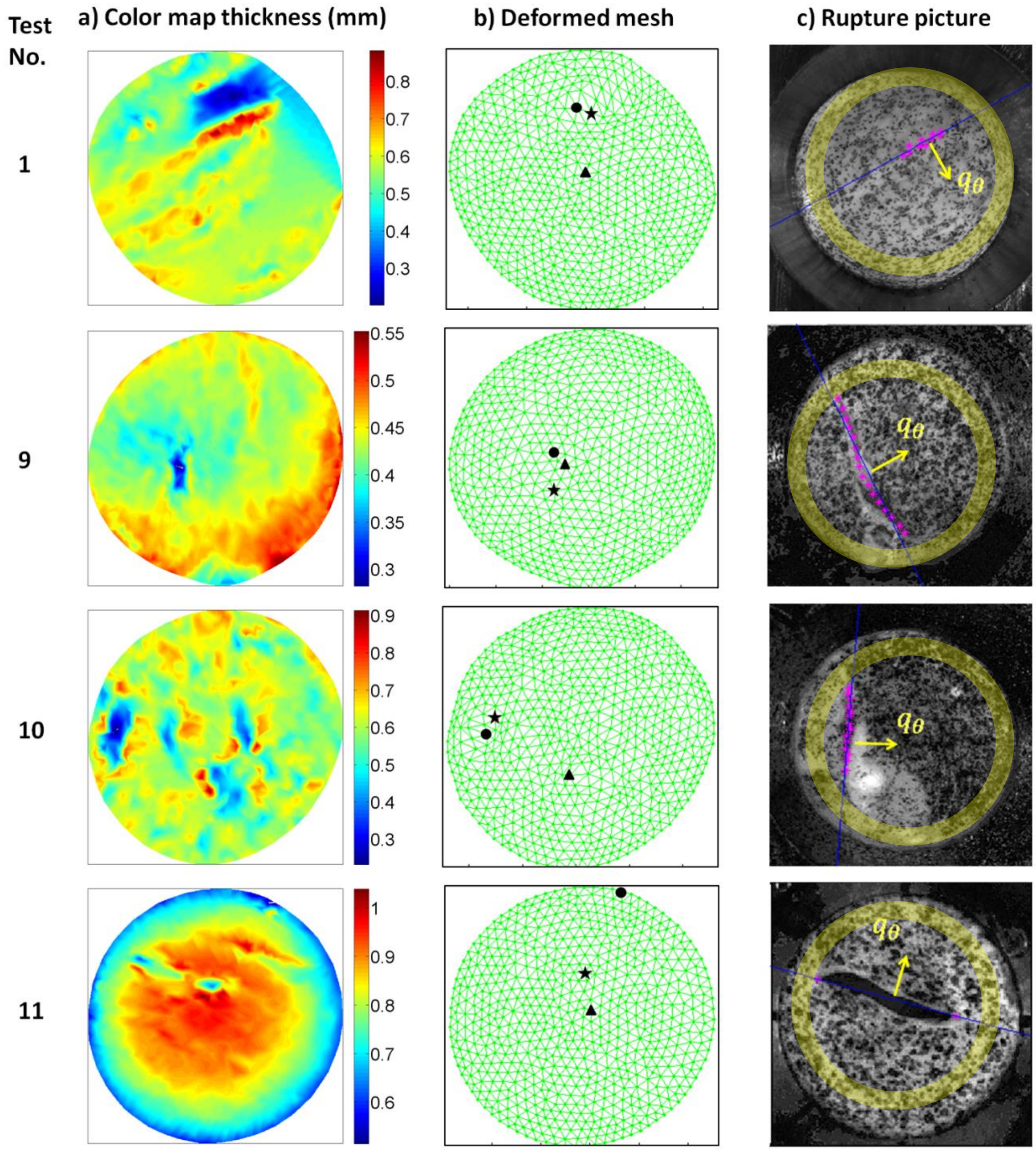
● = NodeMAX
▲ = NodeTOP
★ = NodeRUP

A. Romo, S. Avril, P. Badel, A Duprey, J.P. Favre. In vitro analysis of localized aneurism rupture. Journal of Biomechanics -2014, vol 47, N°3, pp 607-616.

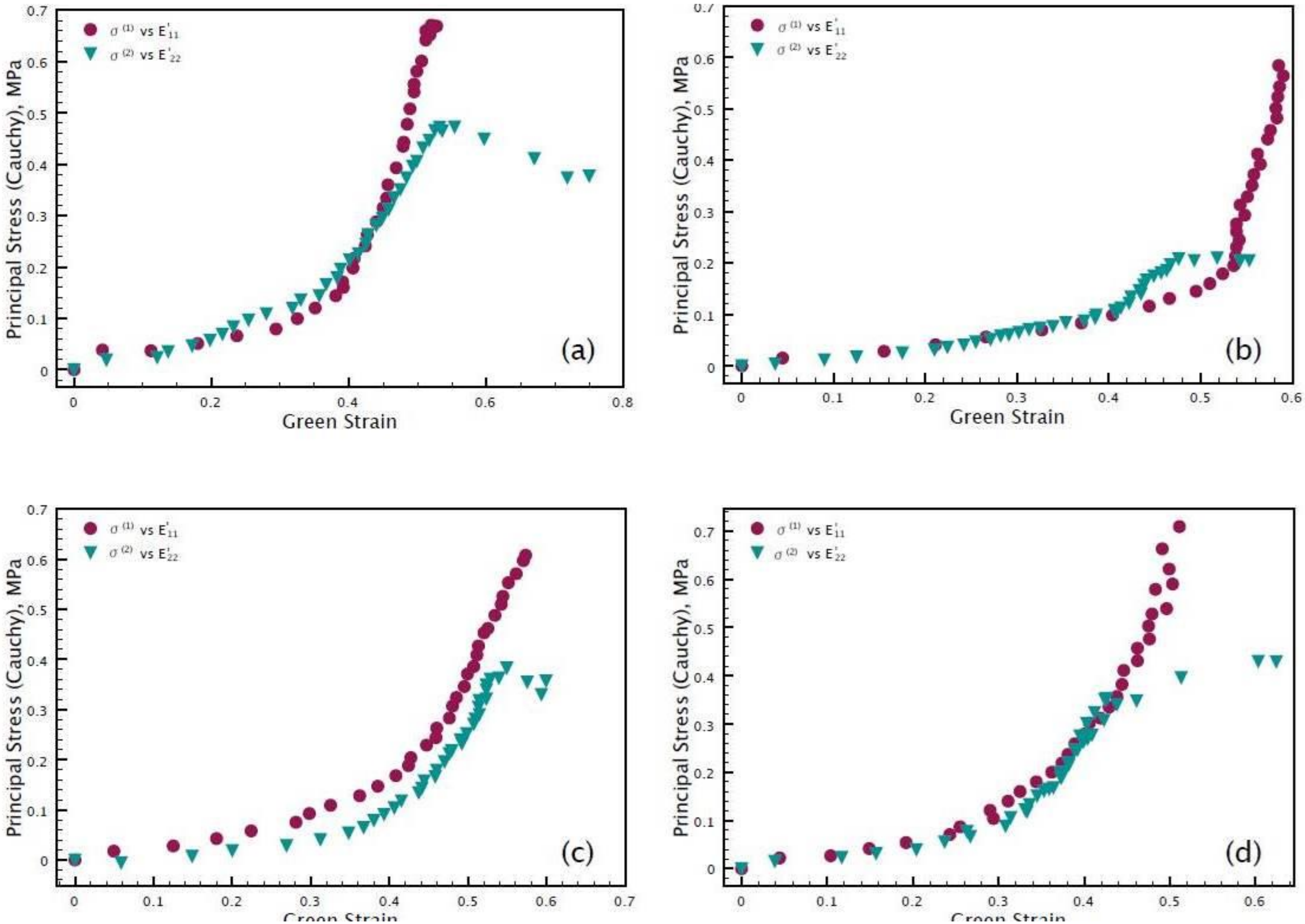
Local damage initiation



Rupture modes

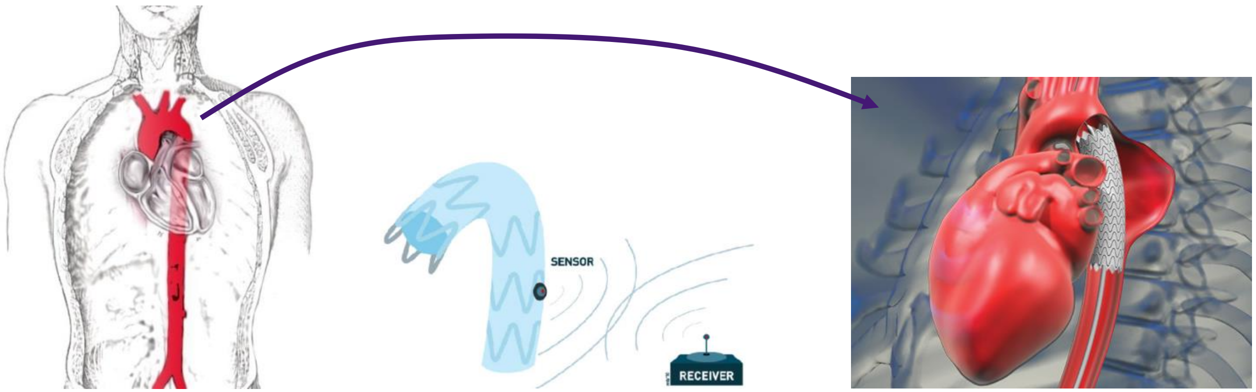


Local stress strain analysis



FUTURE WORK

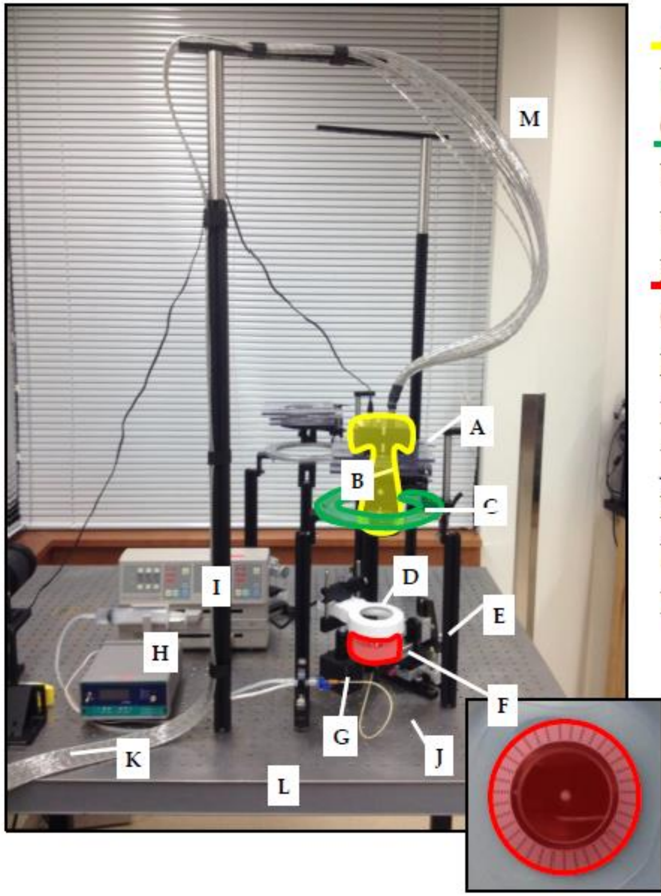
Frontiers of experimental mechanobiology: characterize the local role of mechanical forces and growth factors in the regulation of collagen metabolism



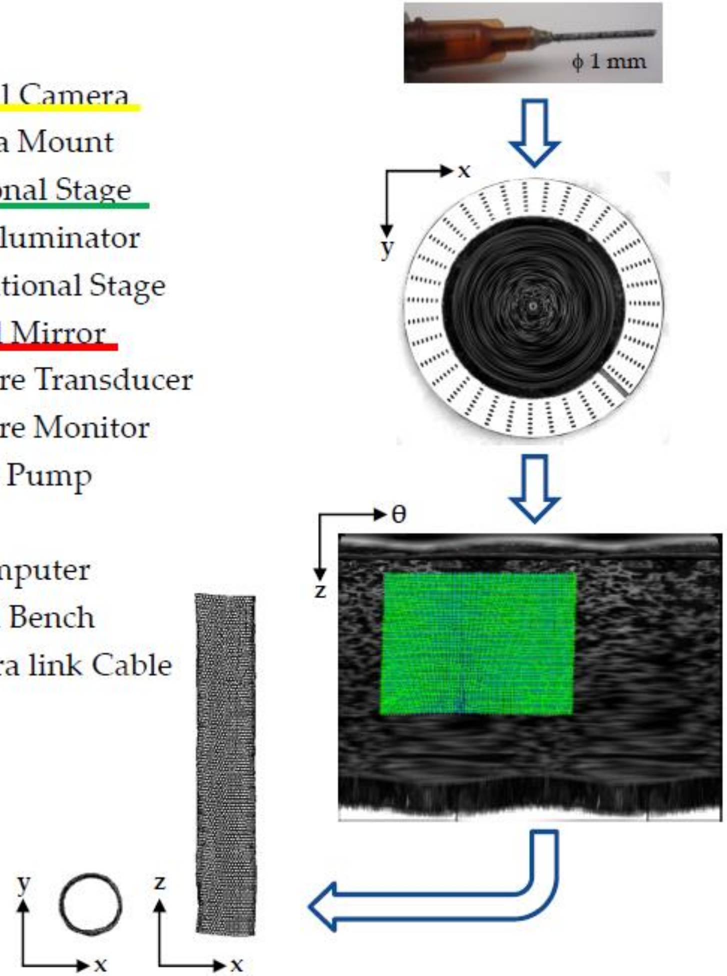
Panoramic digital image correlation

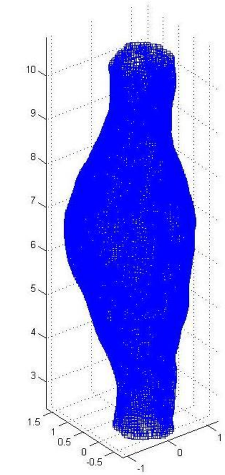
In coll with Prof Jay Humphrey, Yale Univ, USA

- Experimental System



A – Vertical Camera
B – Camera Mount
C – Rotational Stage
D – Ring Illuminator
E – Translational Stage
F – Conical Mirror
G – Pressure Transducer
H – Pressure Monitor
I – Syringe Pump
J – Tubing
K – To Computer
L – Optical Bench
M – Camera link Cable





Genovese et al., JMBBM 2013

Acknowledgements

Invitations

Advanced School on
Material parameter identification and inverse problems in soft tissue biomechanics
Udine (Italy), October 12 - 16, 2015
Contact: avril@emse.fr

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Thank you

INSPIRING INNOVATION INNOVANTE PAR TRADITION