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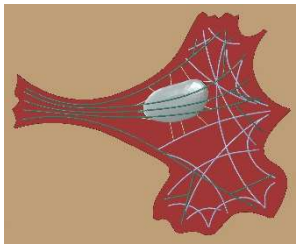

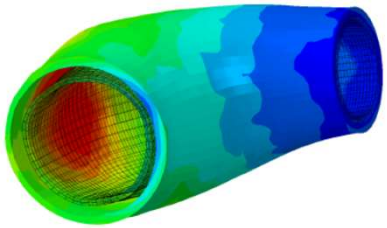

Institut Mines-Télécom

The impact of biomedical engineering and mechanics on vascular health and wellbeing:

DIGITAL TWINS

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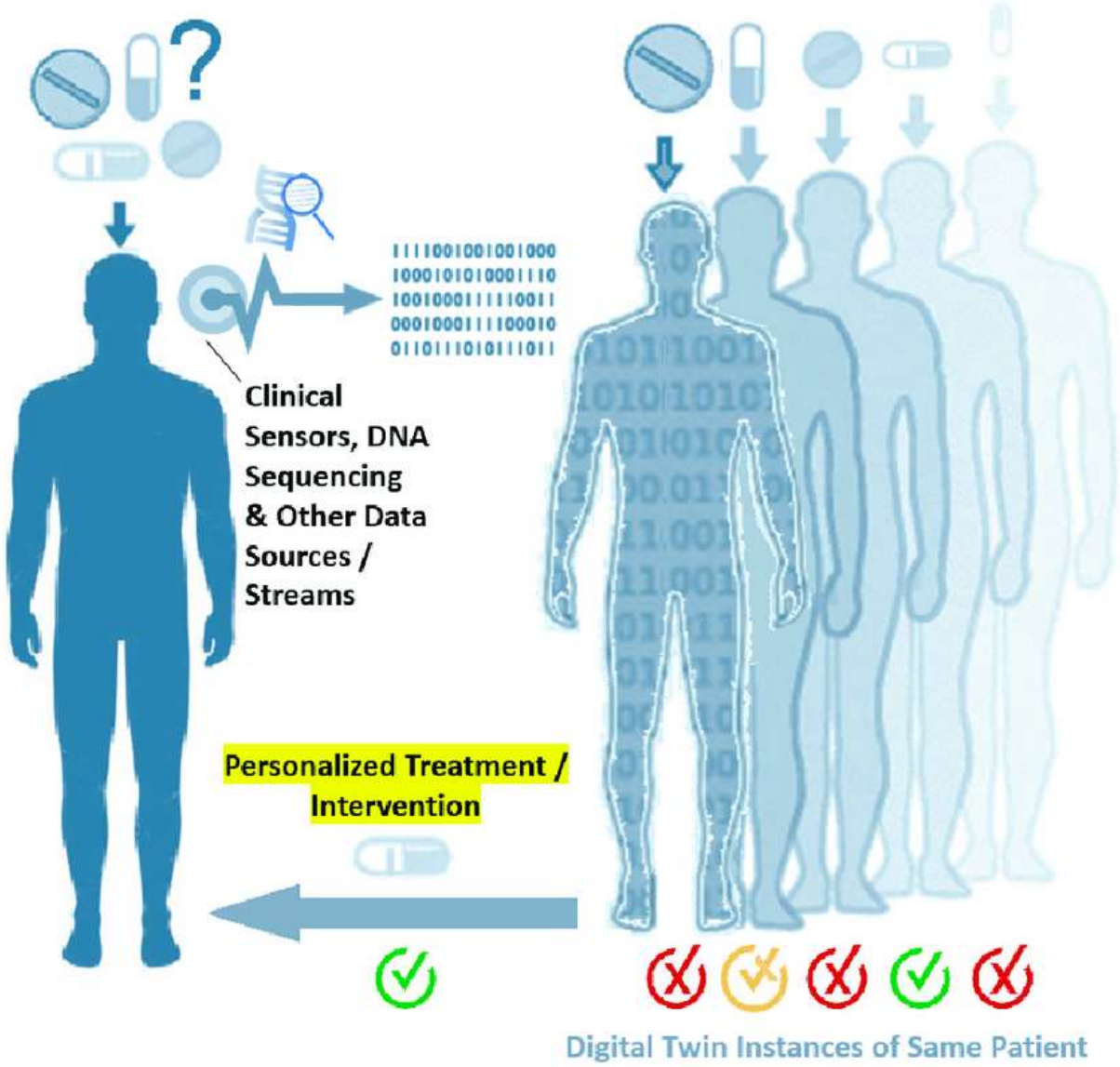
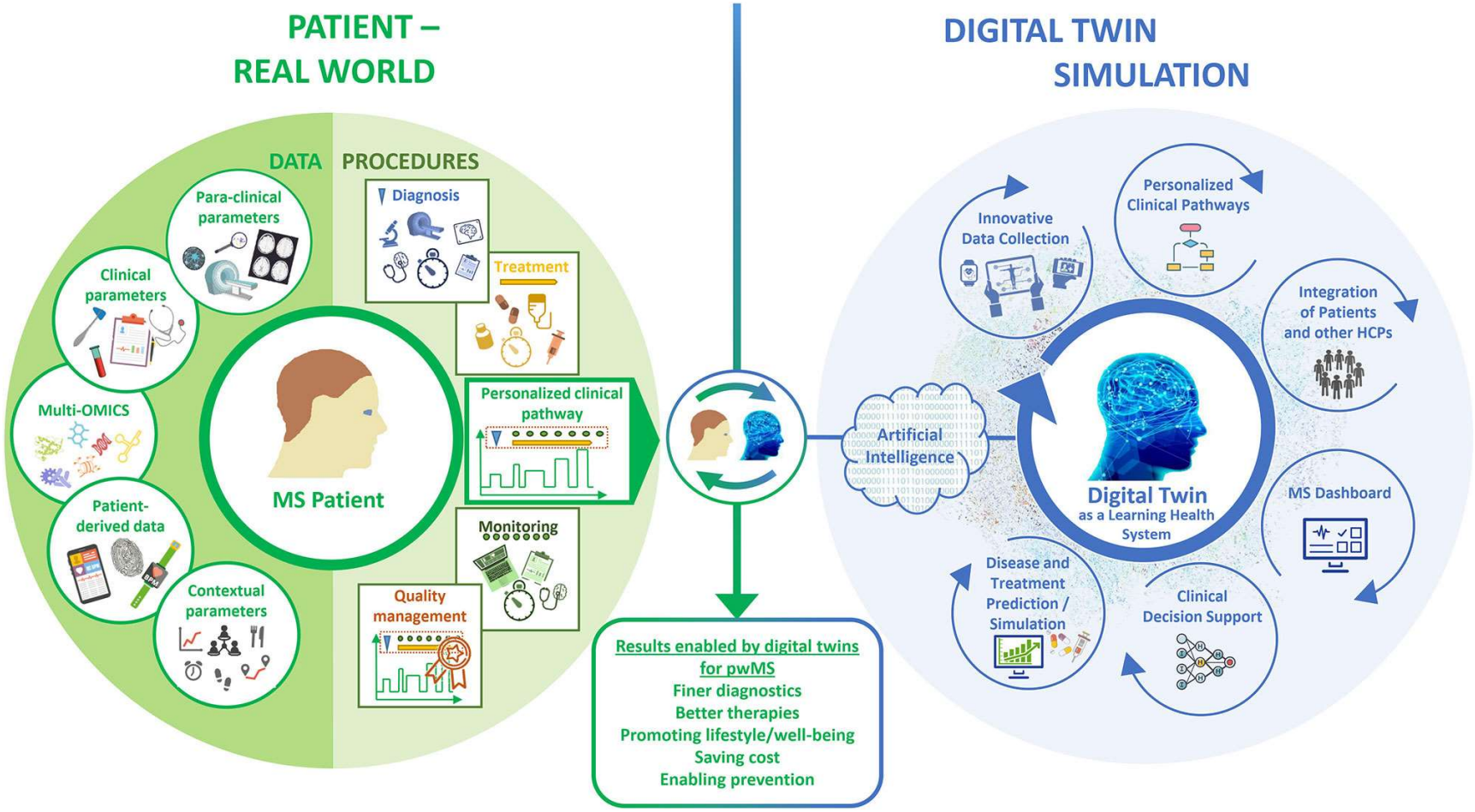
Prof. Stéphane AVRIL

Why Digital Twins can impact human health and well-being ?

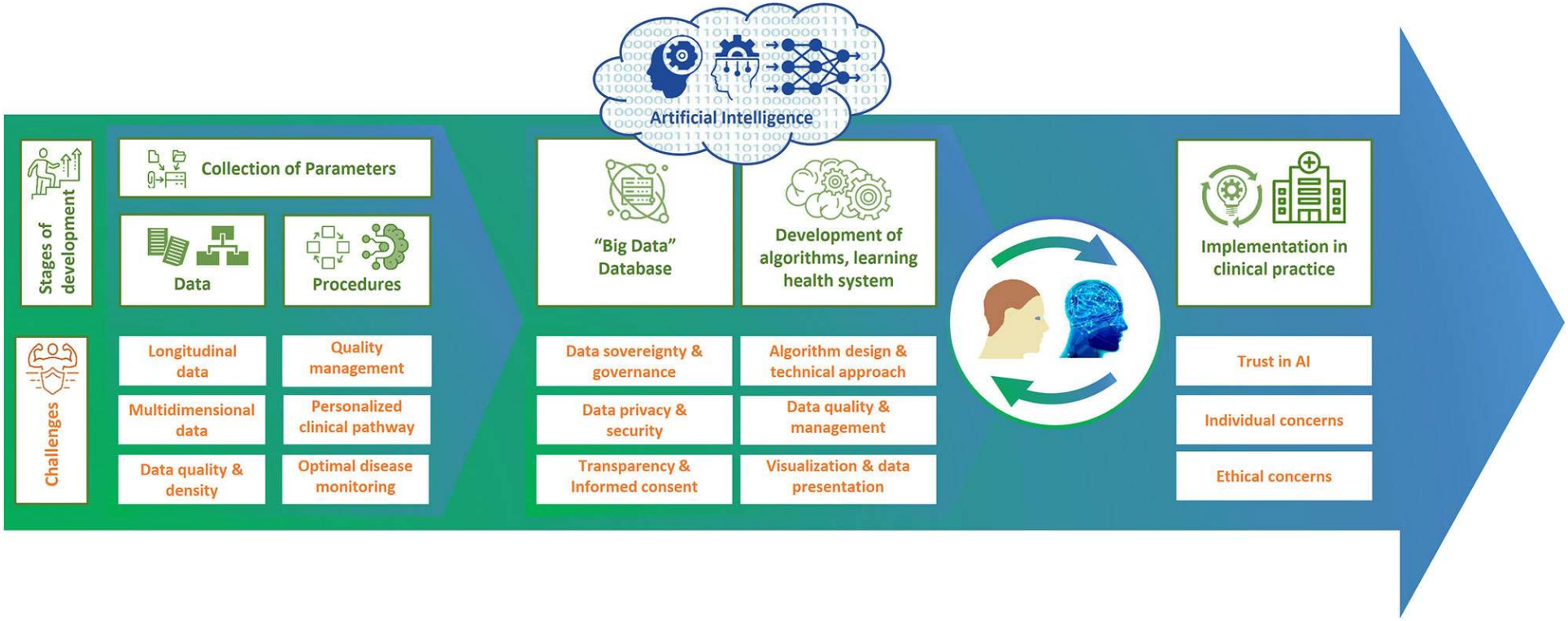


Concept of a digital twin



https://doi.org/10.3389/fimmu.2021.669811

Time-Flow for Digital Twins



https://doi.org/10.3389/fimmu.2021.669811

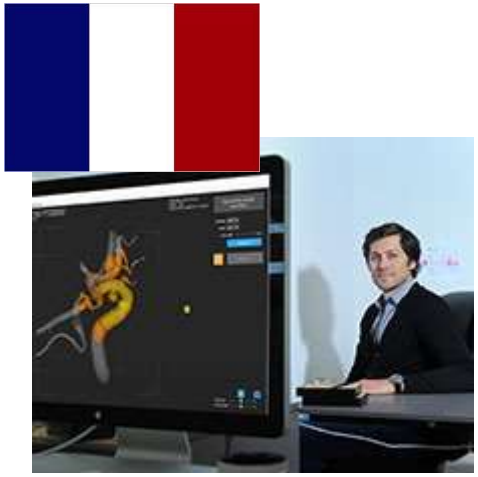
Successful digital twins in medicine

2014: FDA allows marketing of HeartFlow vFFR-CT tool for optimal treatment of coronary stenosis

Gaus S, *et al*, JCCT 2013, 7(5):279-88.

2019: FEops HEARTguide in silico tool for planning transcatheter aortic valve implantation is CE-marked

El Faquir N, *et al* Int J Cardiov Img 2019



2014: Sim&Cure

2017: Predisurge

Derycke, *et al* Circulation Img 2021

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My own experience

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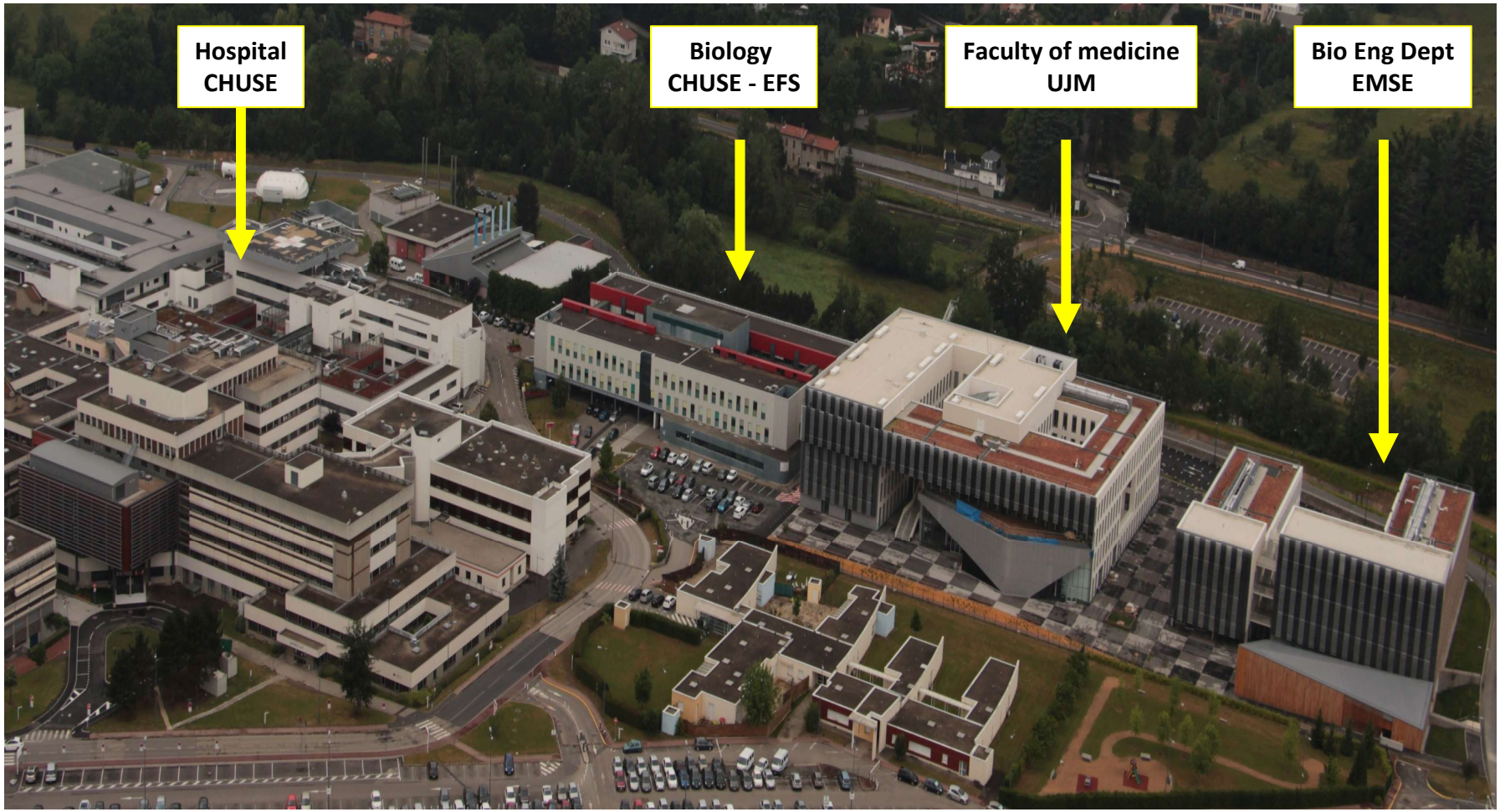

« Where engineers, biologists and physicians meet together to improve health »

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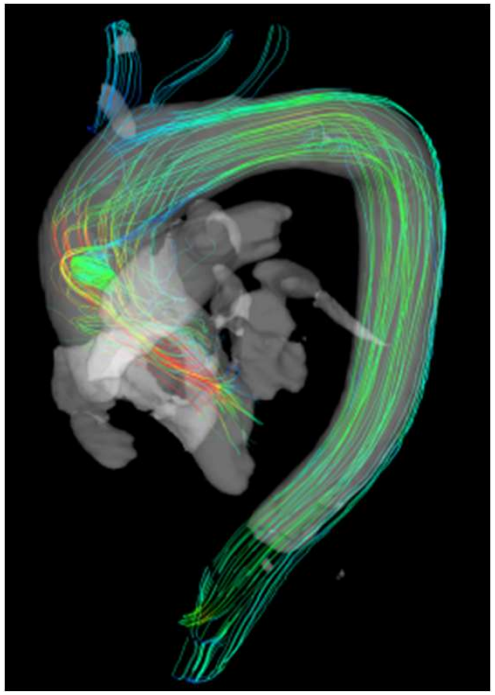
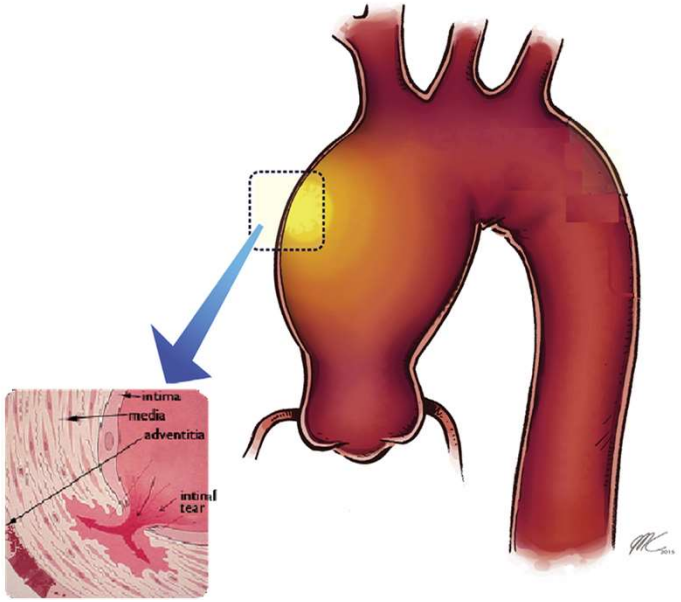
4 teams:

- **STBio:** soft tissue biomechanics
- **BioMat:** engineering of biomat
- **BioPI:** inhaled particles
- **I4S:** engineering of care systems

Aneurysms and Dissections of the aorta





== Devastating complications!

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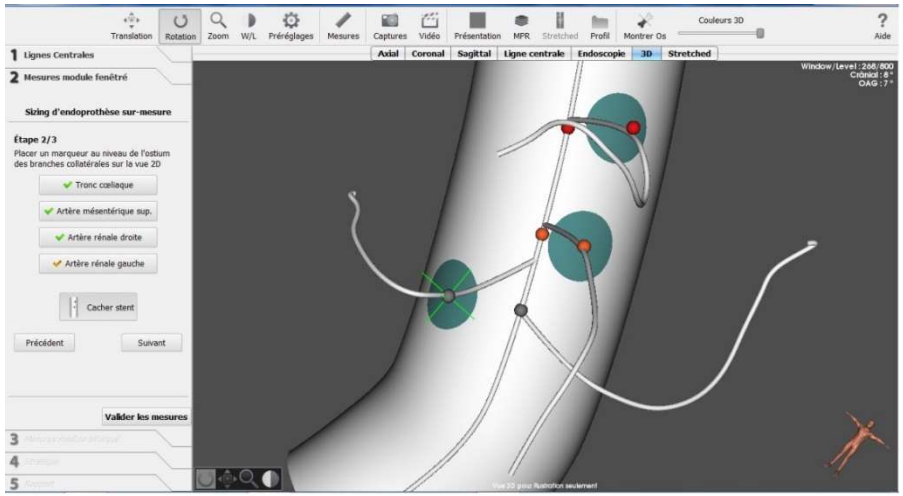
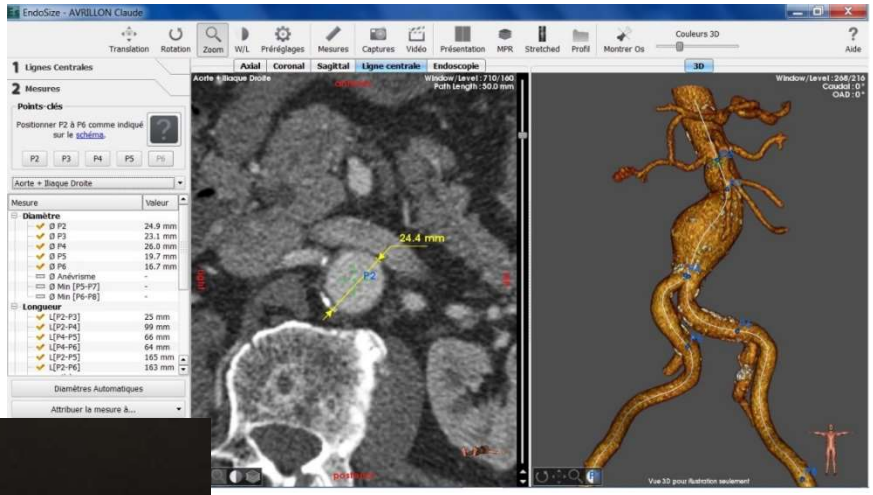
STEP 1

Our first goal was to develop computer models to assist surgical interventions on aortic aneurysms

2010

Planification / sizing of fenestrated stent grafts in EVAR procedures





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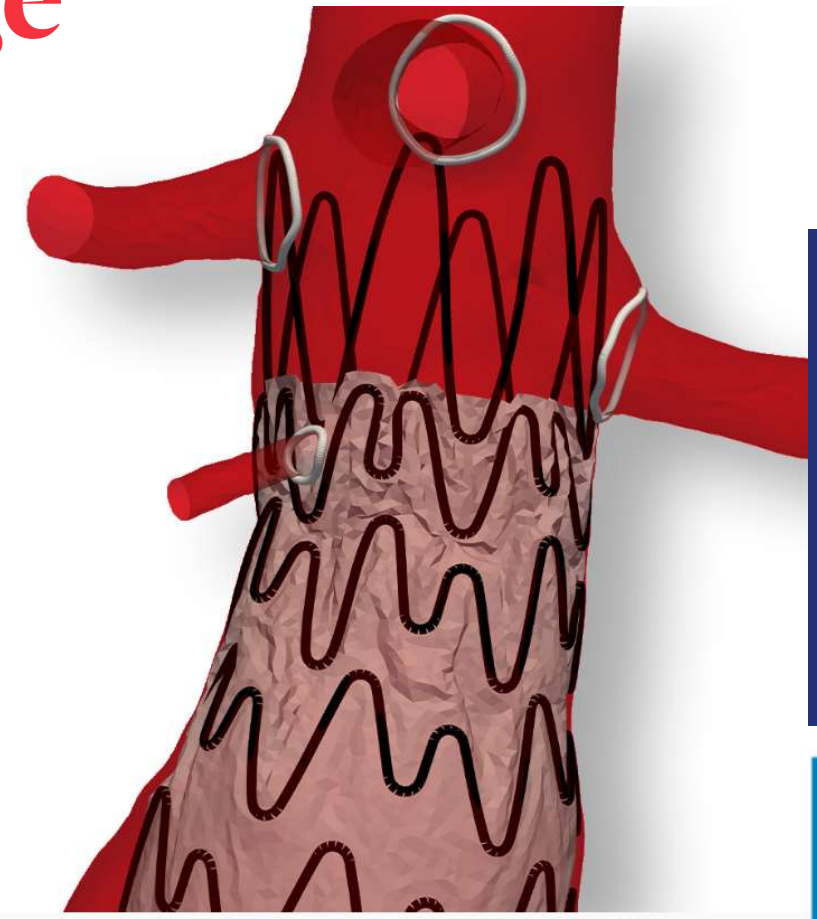
The solution with a digital twin

PrediSurge

Changing patients lives with digital twin technology

Predictive Simulation for Cardiovascular Intervention

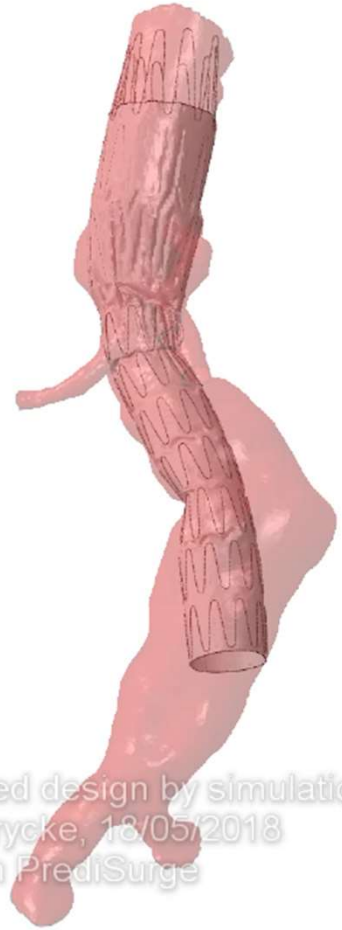
LEARN MORE

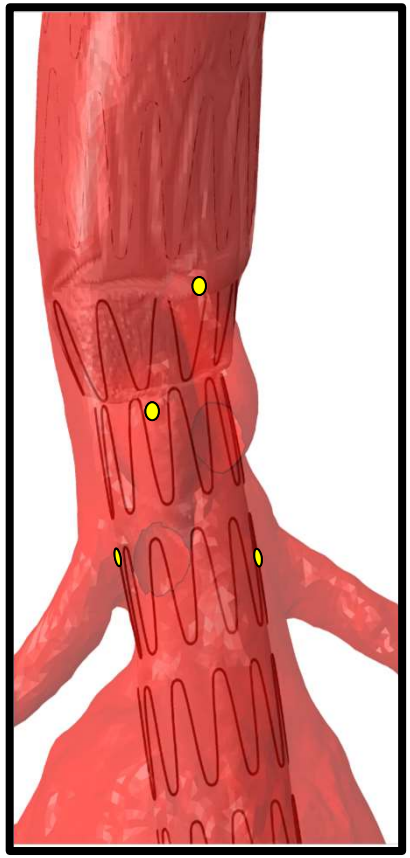


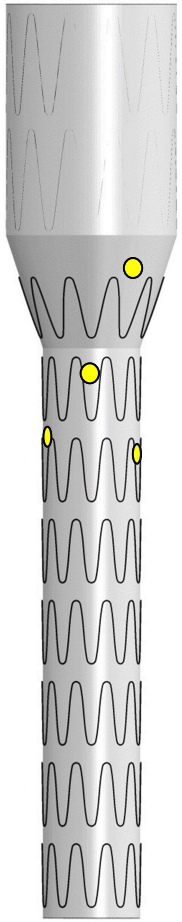
FDA

www.predisurge.com

Clinically validated for FEVAR Zenith® Cook Medical

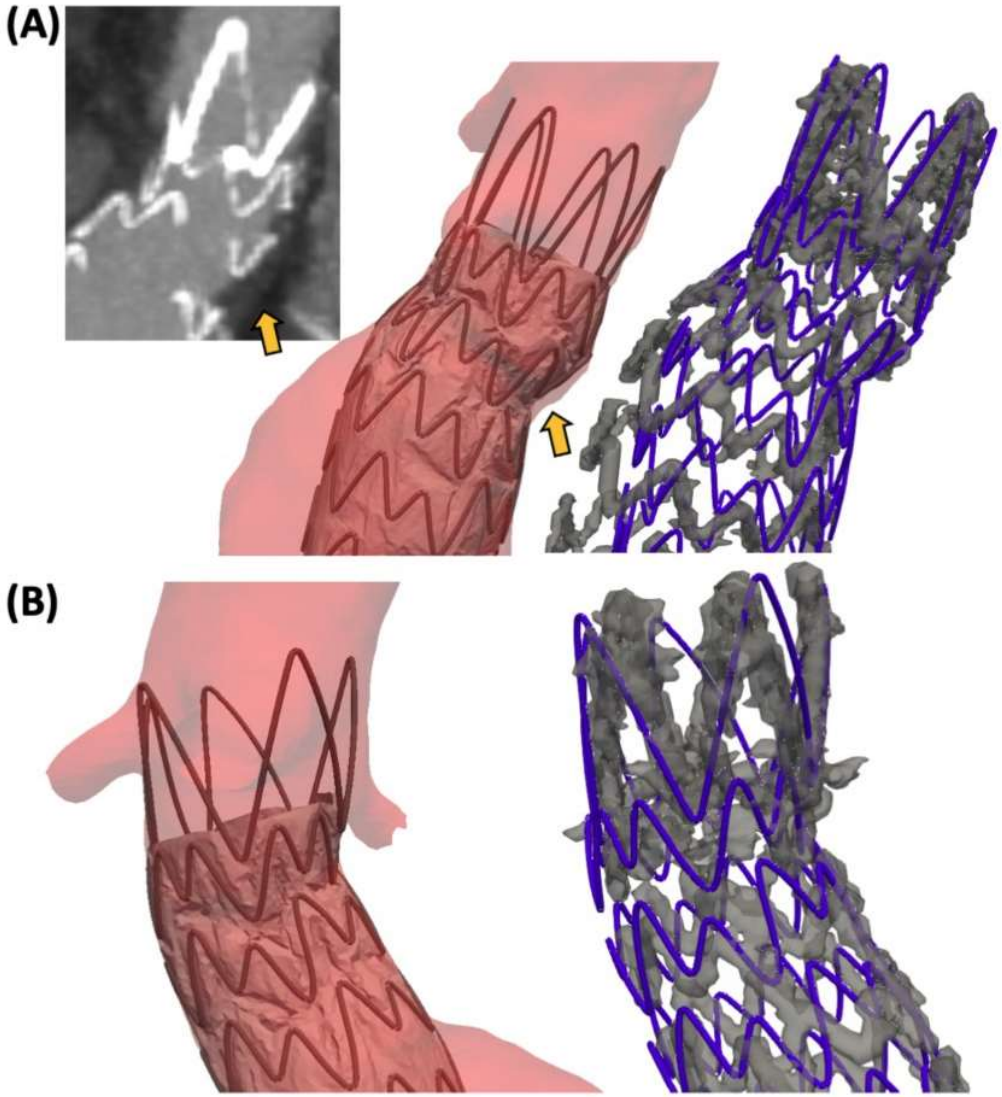






Prevention of endoleaks

Computer Methods and Programs in Biomedicine 244, 107993



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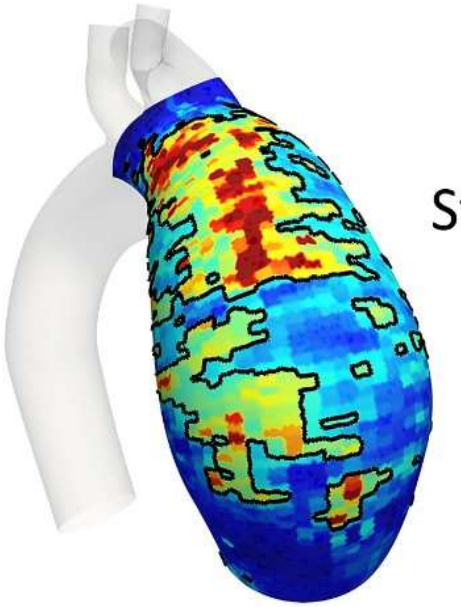
STEP 2

Our next goal was to develop patient-specific computer models of aneurysm growth…

2010 2015

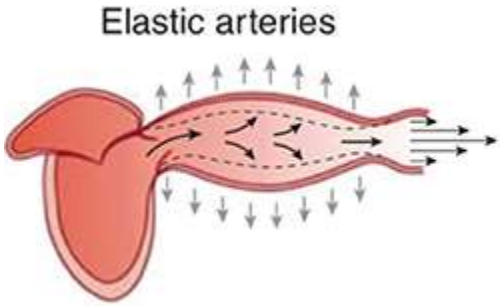
Local stiffening related to locally altered hemodynamics

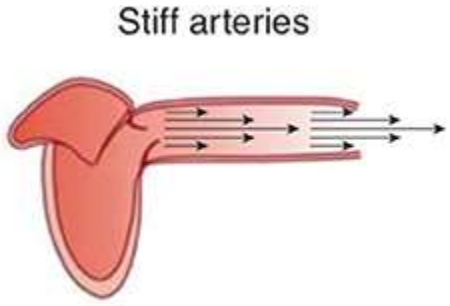


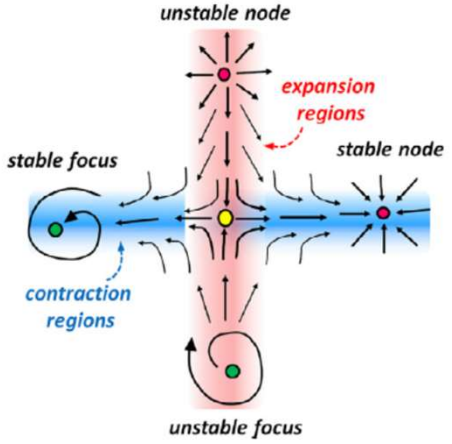
Stiffness
[N mm^{-1}]
20.0
10.0
1.0

WSS fixed points weighted residence time

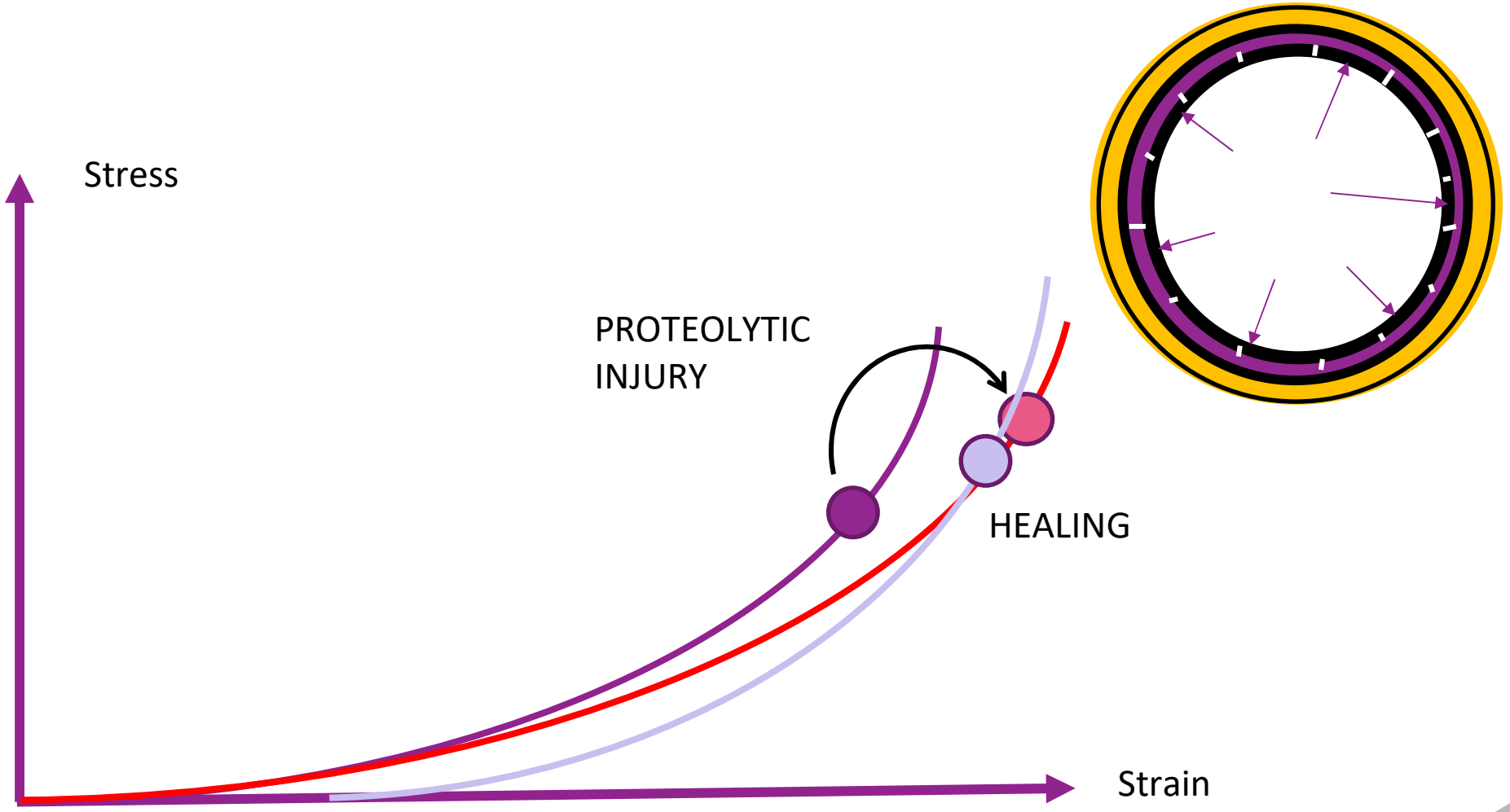
$RT\nabla_{x_{fp}}$
[Pa m^{-1}]
2e+5
1e+5
0e+5

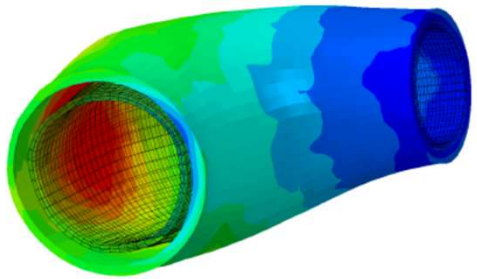




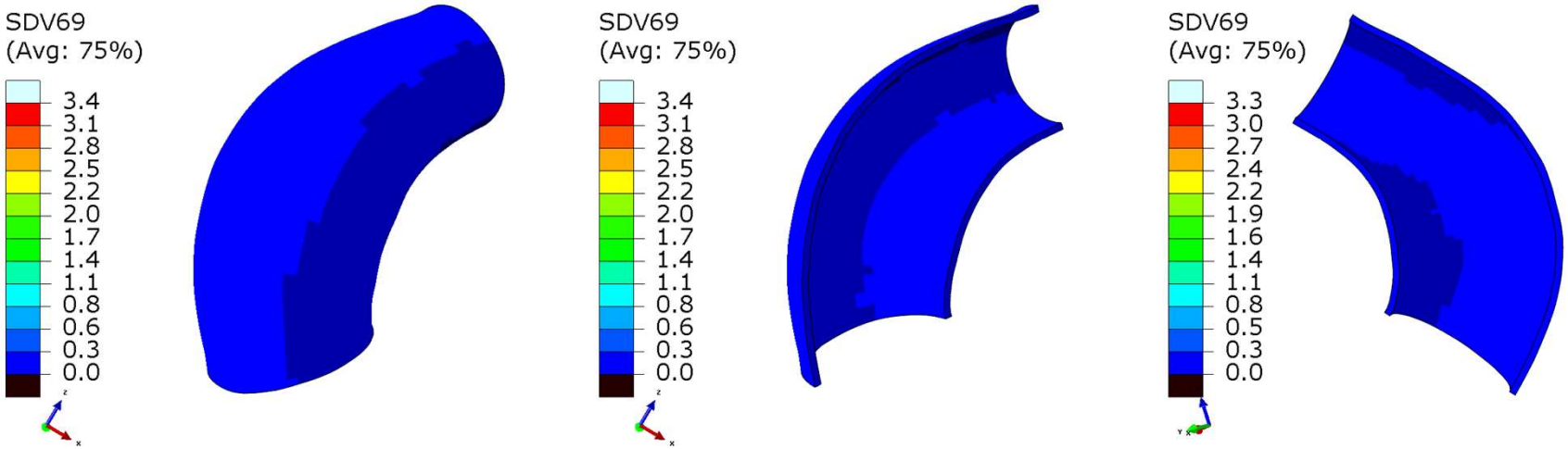


Mechanical model





Computer model of aneurysm growth

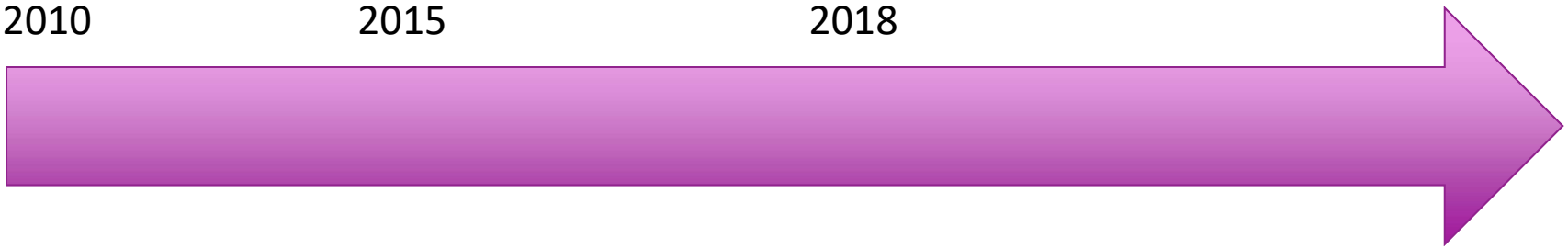


Normalized Thickness

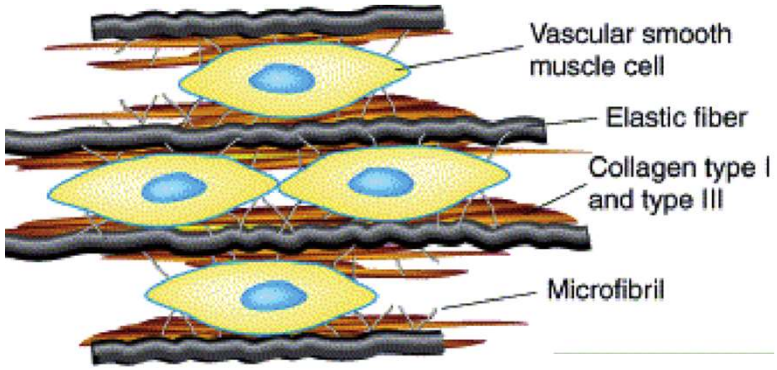
Mousavi et al, BMMB (2019)

STEP 3

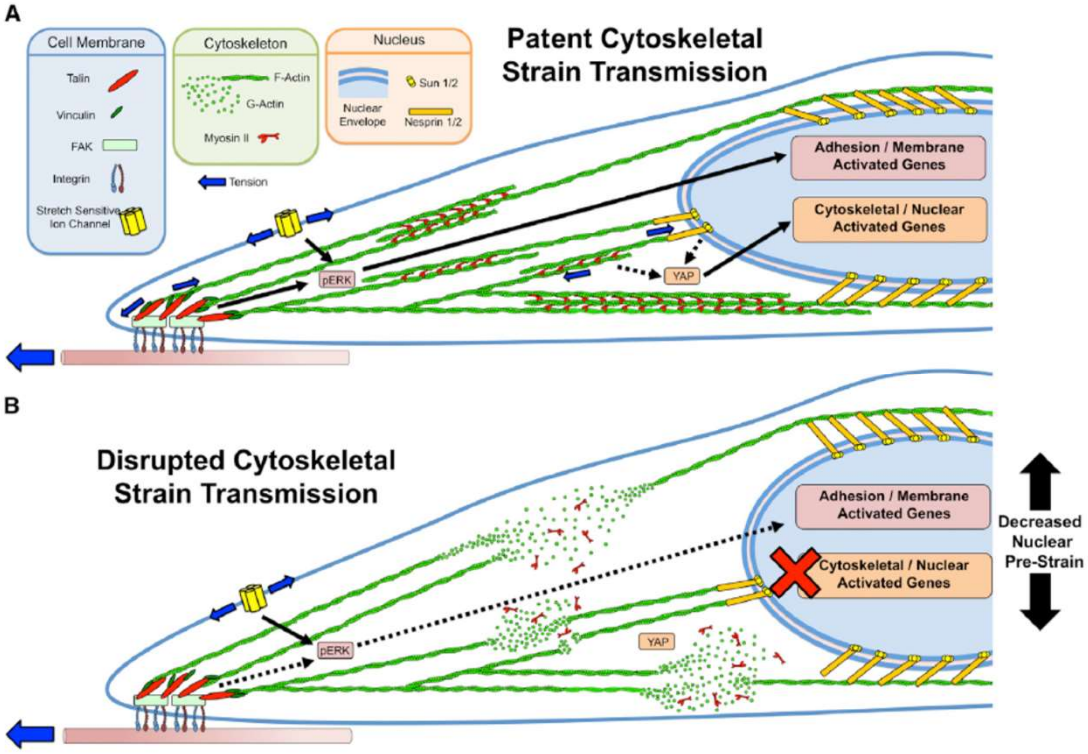
Our next goal was to integrate more biology in our computer models

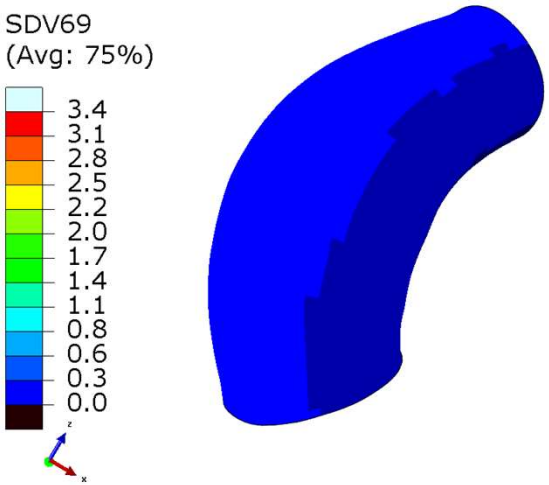


Major role of smooth muscle cells in mechanoregulation

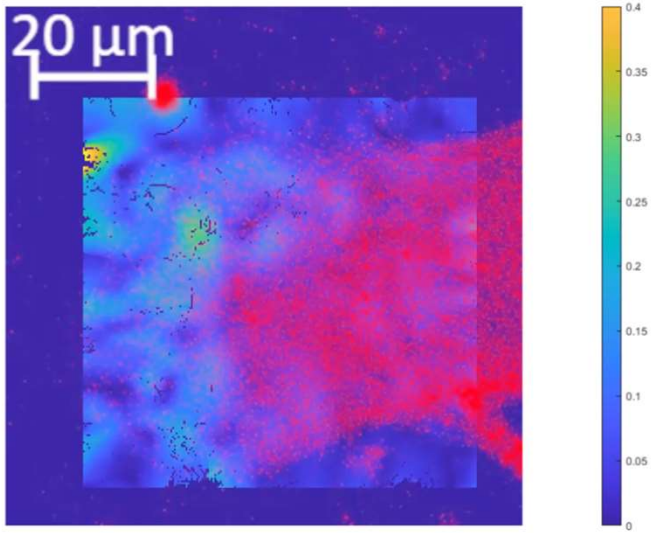


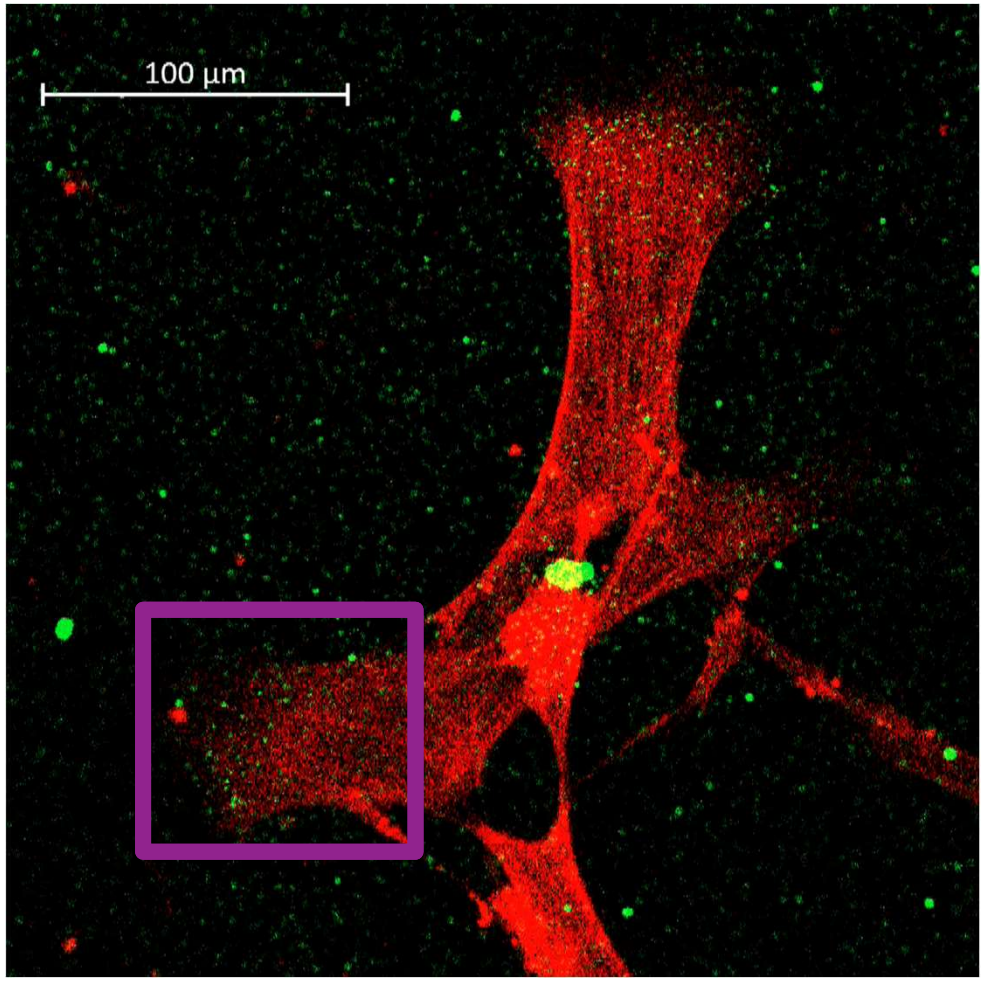
Driscoll et al, Biophysical Journal, 2015





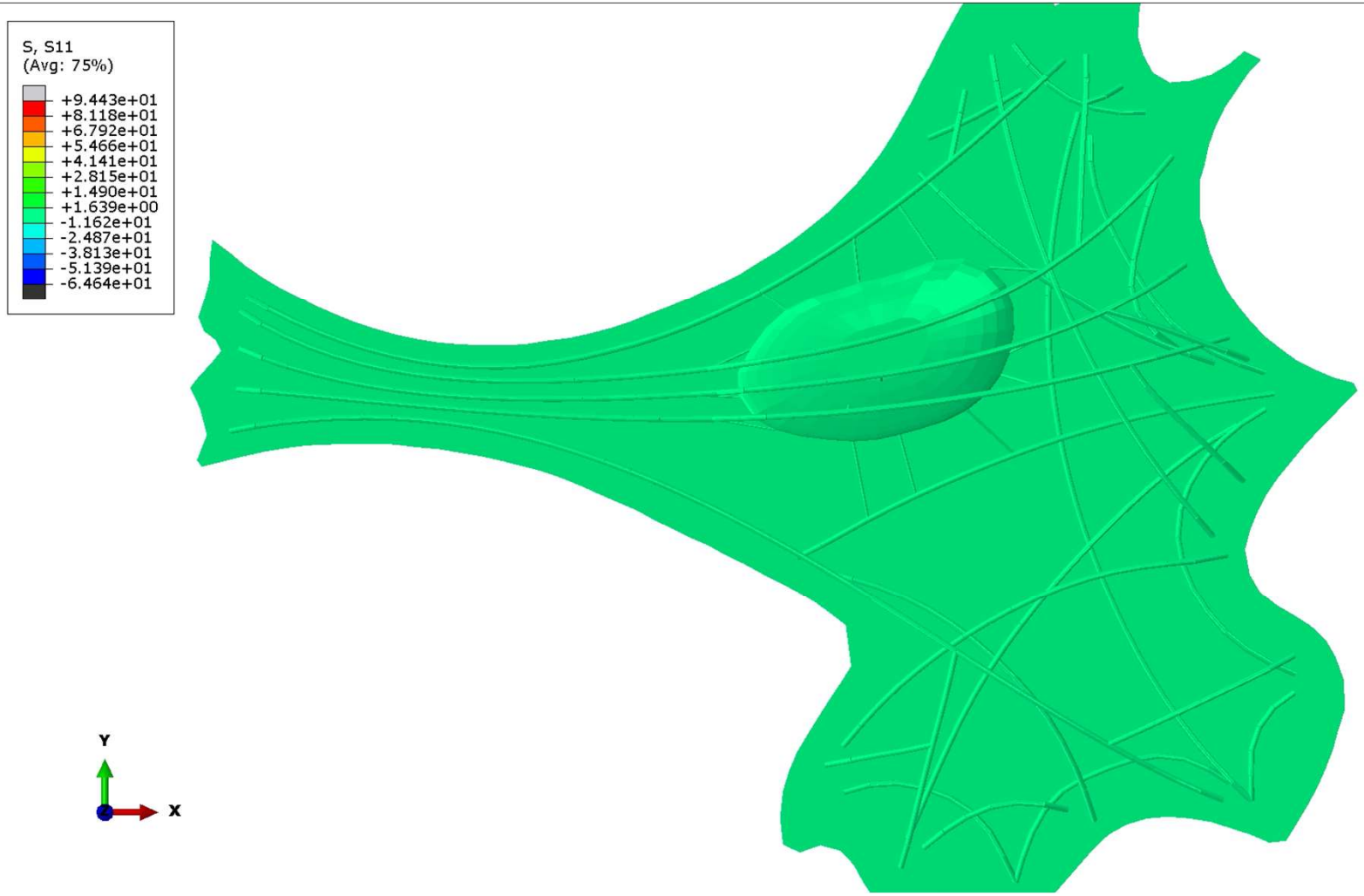
Mechanobiology of aortic SMCs



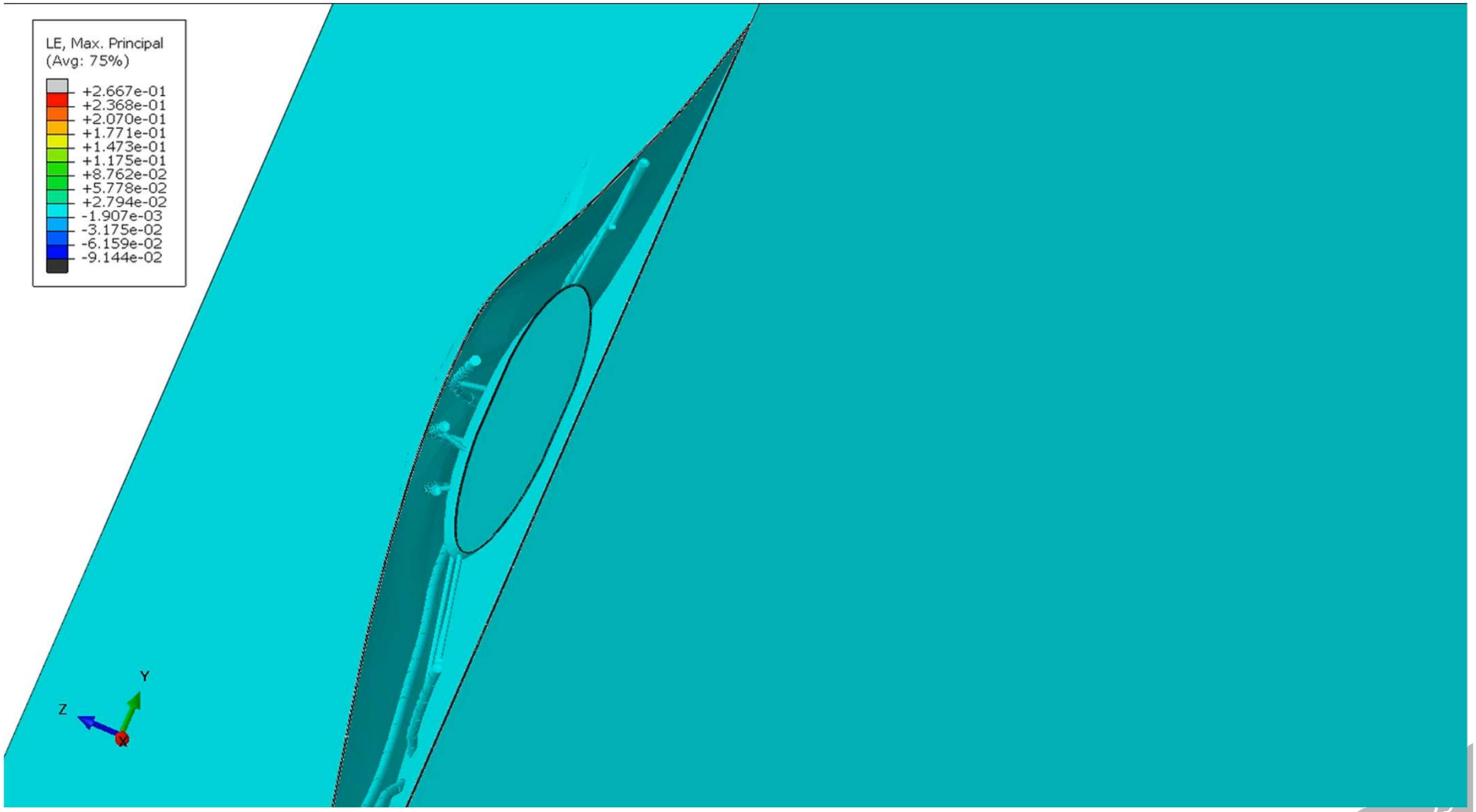


Confocal microscopy + DIC combined with Siractin staining on living cells

Computer model of SMCs

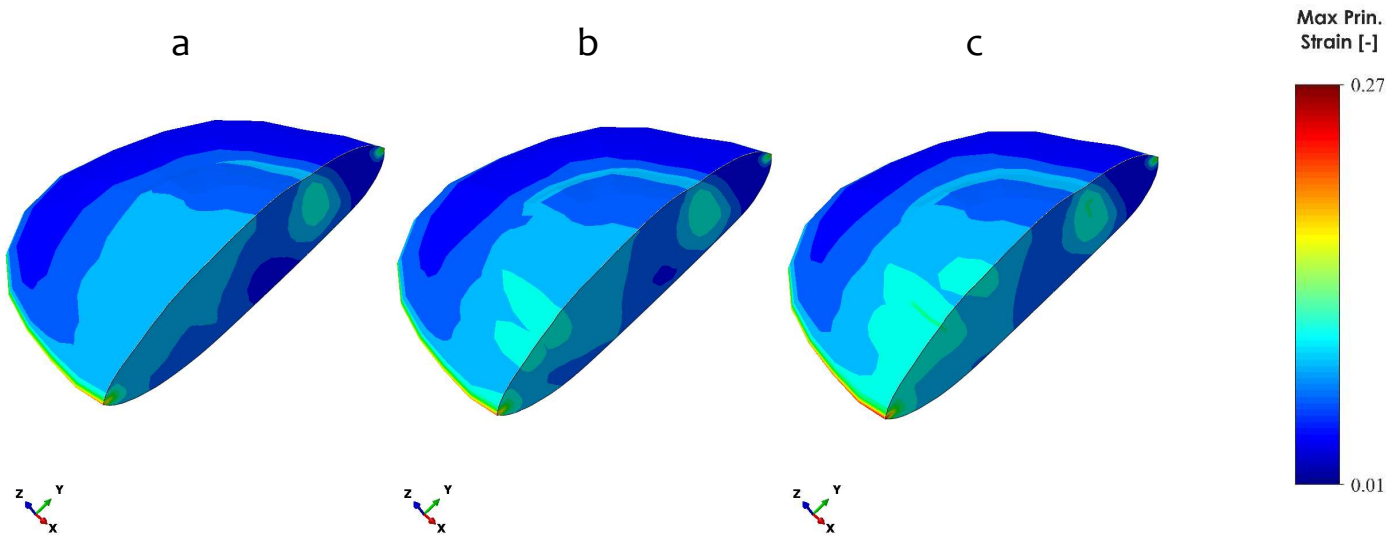


Computer model of SMCs



Computer model of SMCs

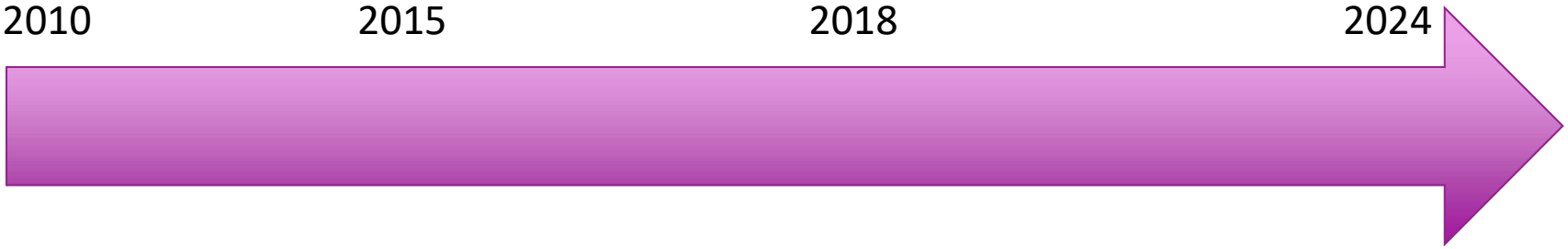
Strain map in the cell nucleus



Distribution of the maximum principal strain in half of the nucleus for substrates with Young's moduli of 2 kPa (a), 4 kPa (b), and 8 kPa (c).

STEP 4

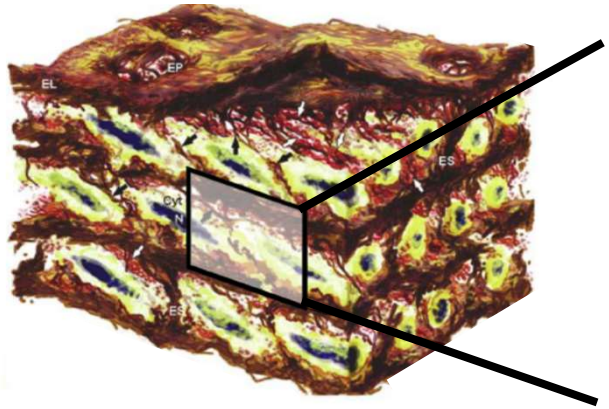
Our future goal was to screen treatments to fight against vascular aging



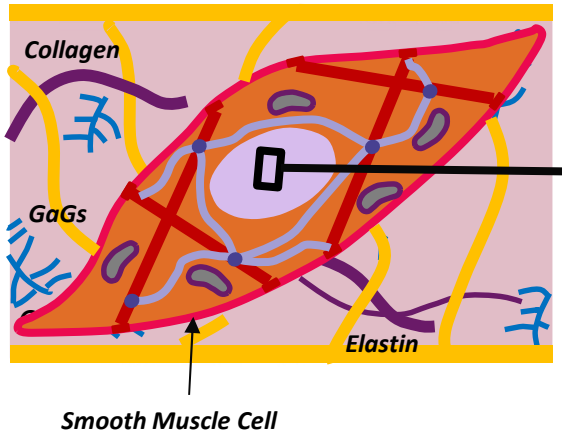
MULTISCALE DIGITAL TWINS

Altered feedback loops

Regulation of gene expressions



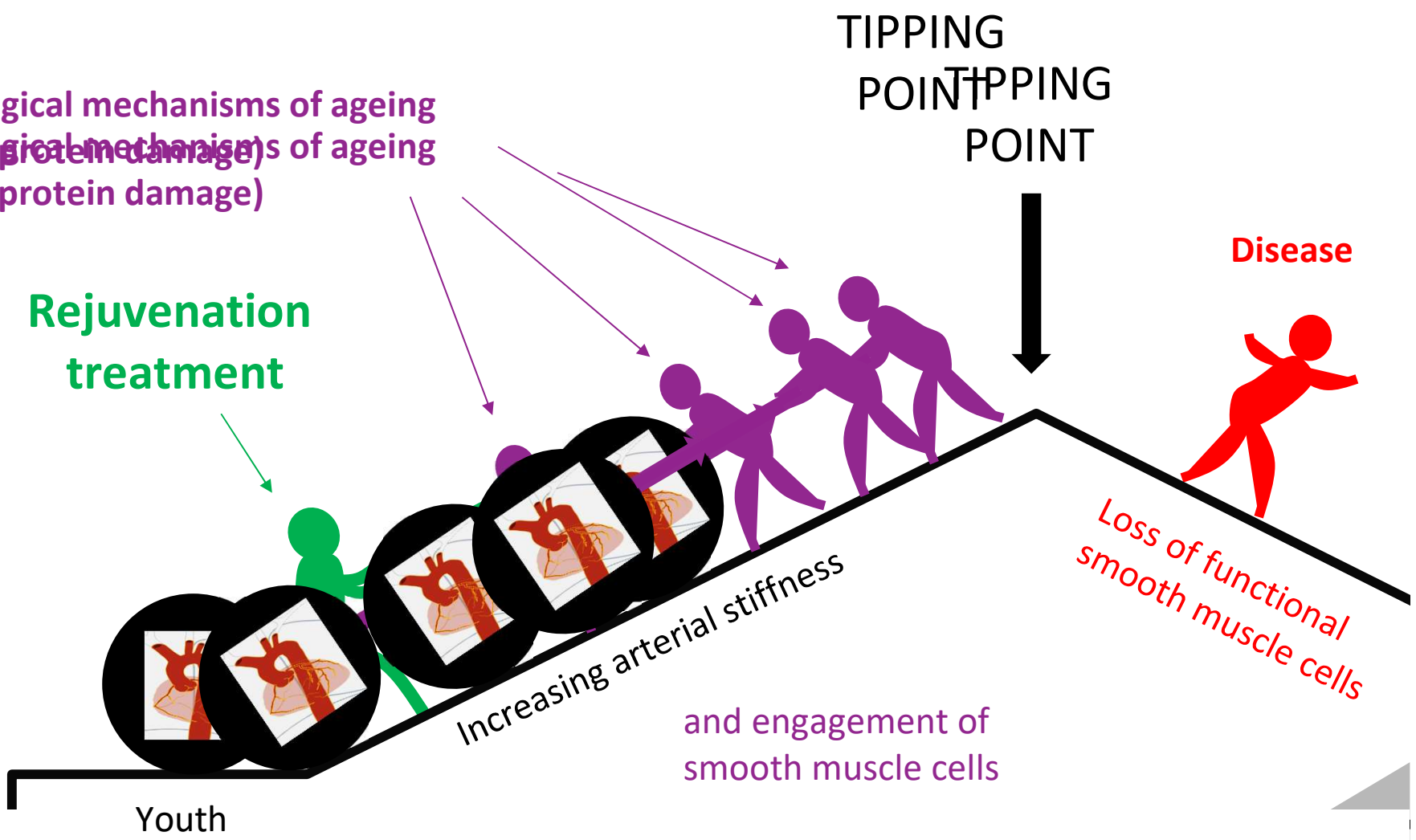
Lamellar unit



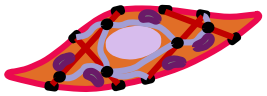
Altered micromechanics

Altered gene expressions

STEP 4

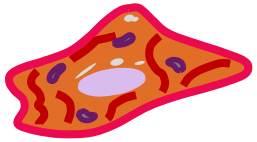

TIPPING POINT
TIPPING POINT
Biological mechanisms of ageing (e.g. protein damage)
Biological mechanisms of ageing (e.g. protein damage)
Rejuvenation treatment
Disease
Increasing arterial stiffness
and engagement of smooth muscle cells
Loss of functional smooth muscle cells
Youth
Senescent Cell

SCREENING REJUVENATION TREATMENTS WITH MULTISCALE DIGITAL TWINS



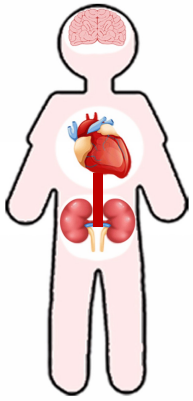
Functional
Smooth Muscle Cell

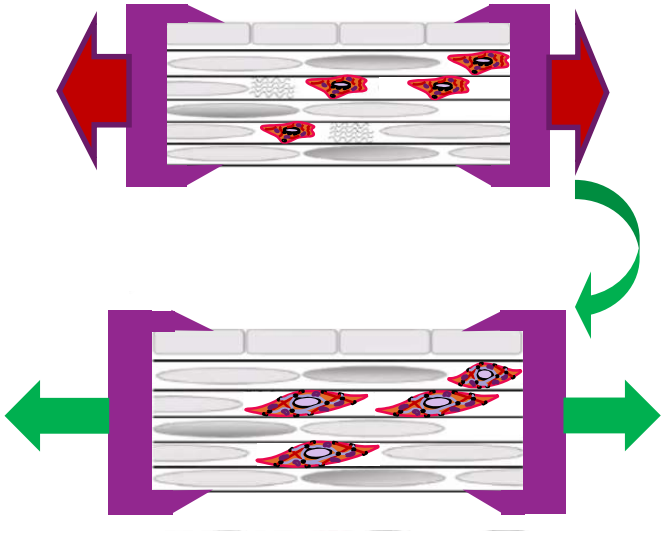
REJUVENATION

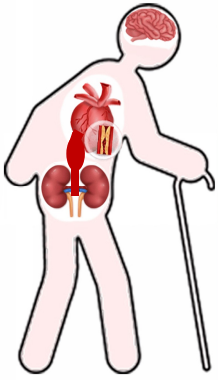


Senescent
Cell

AGEING







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