




From stent deployment to flow analysis: assumptions, limitations

Gabriele Dubini

Politecnico di Milano

Where we were

EBC 2012 – presentation by Stefano Morlacchi

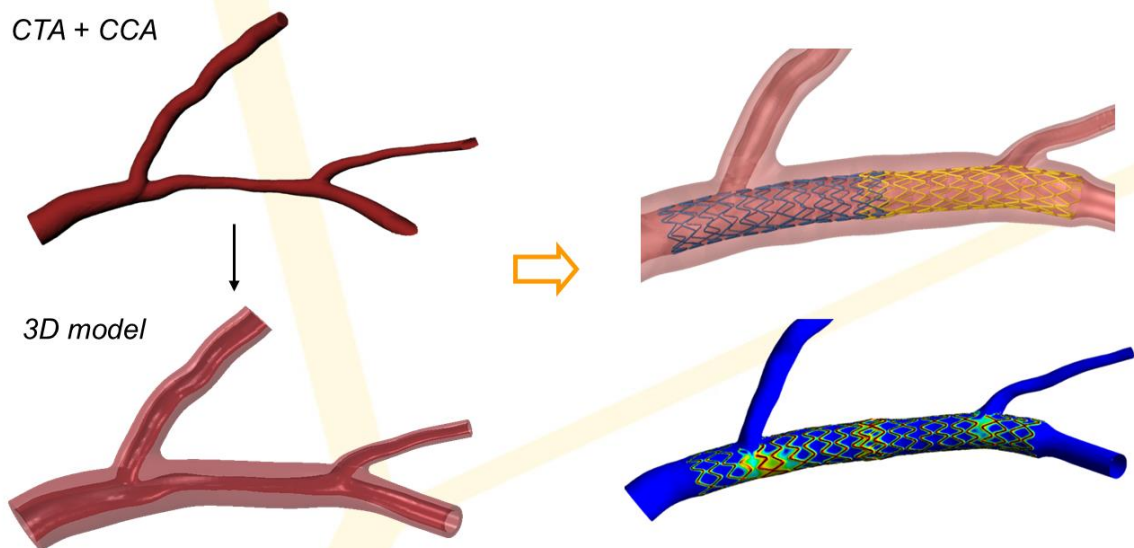


Further developments

Image-based simulations of clinical cases.

CTA + CCA

3D model



The diagram illustrates the process of image-based simulations. It starts with a 3D reconstruction of a bifurcated artery from CTA and CCA data. This is followed by the creation of a 3D model of the artery. The final step shows the simulation of a stent placement in the artery, with the stent represented by a yellow mesh and the resulting flow field visualized in blue and green.

In collaboration with Universitat Pompeu Fabra, Barcelona.

Where we are

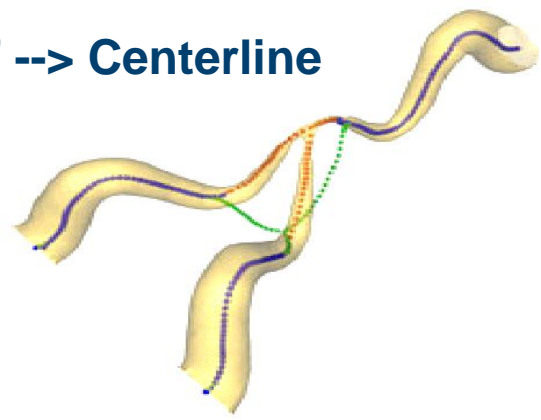
Internal surface
reconstruction

3D solid model

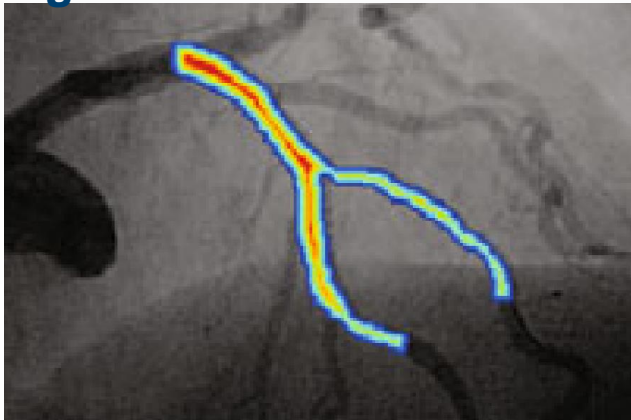
Discretization

Plaque
identification

CT --> Centerline



Angio --> Diameters



Where we are

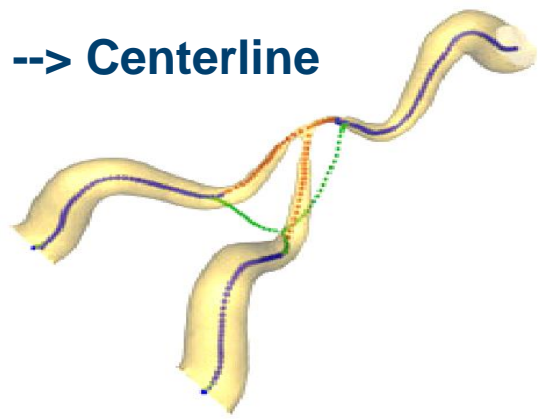
Internal surface reconstruction

3D solid model

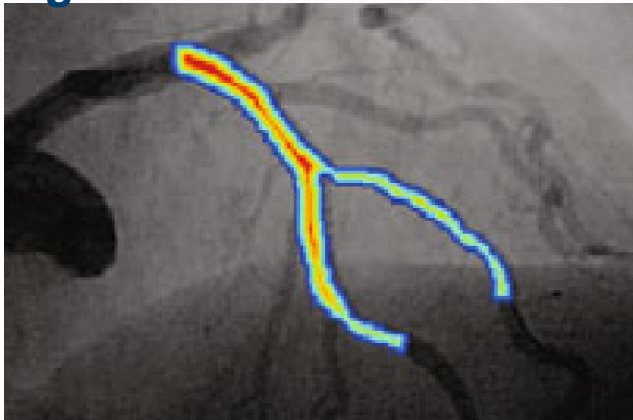
Discretization

Plaque identification

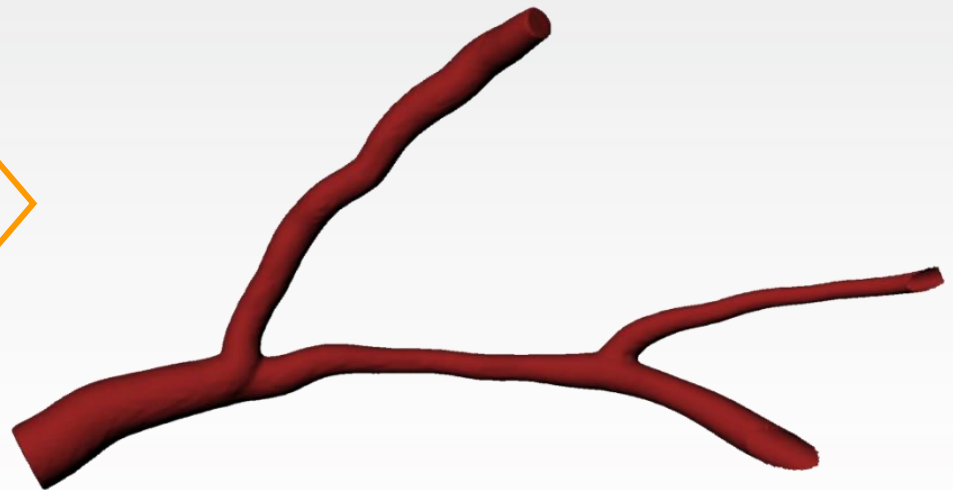
CT --> Centerline



Angio --> Diameters

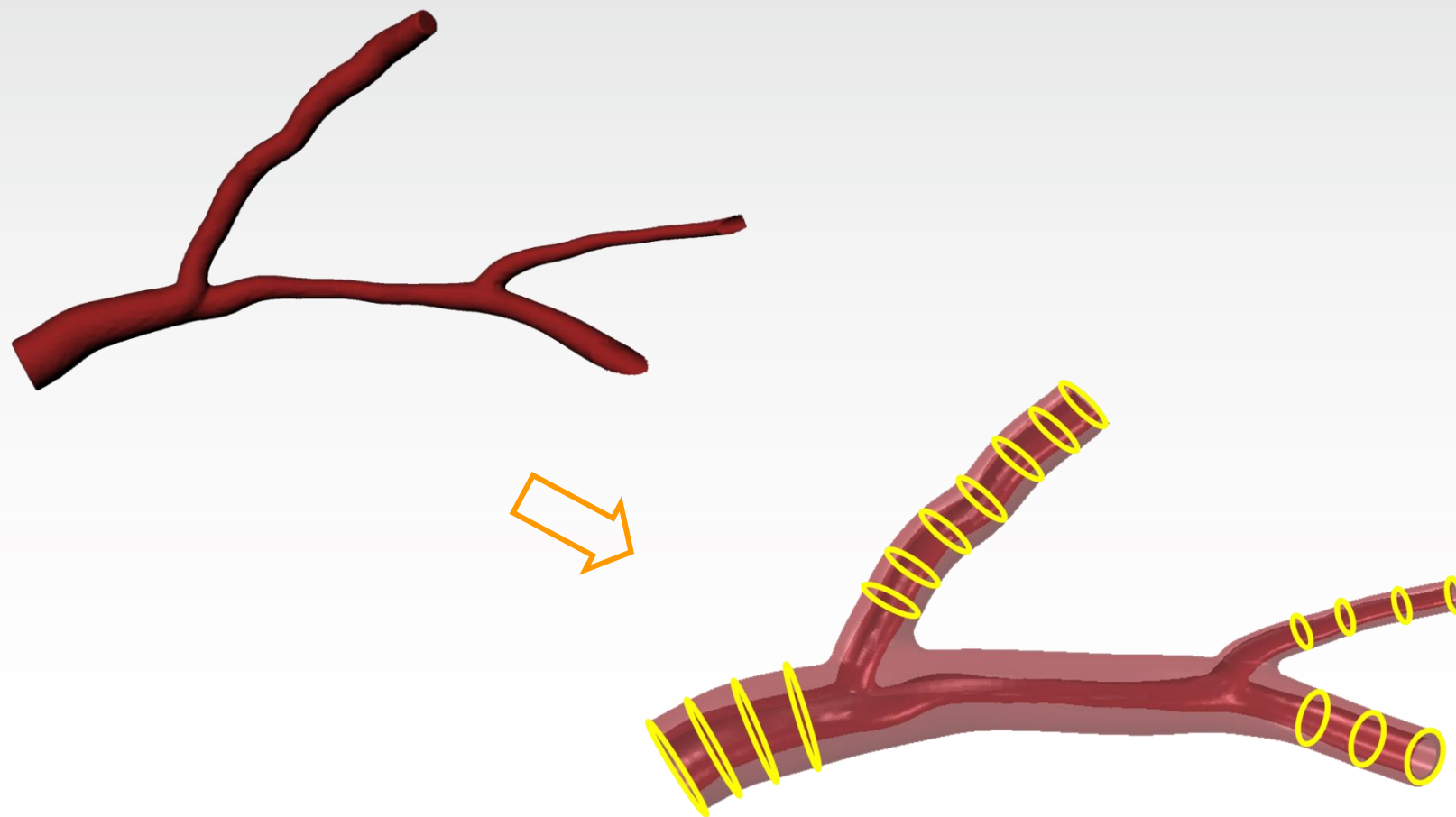


Internal surface of LAD artery



(Cárdenes et al. "3D modeling of coronary artery bifurcations from CTA and conventional coronary angiography". *Med Image Comput Comput Assist Interv.* 2011;14(Pt 3):395-402)

Where we are



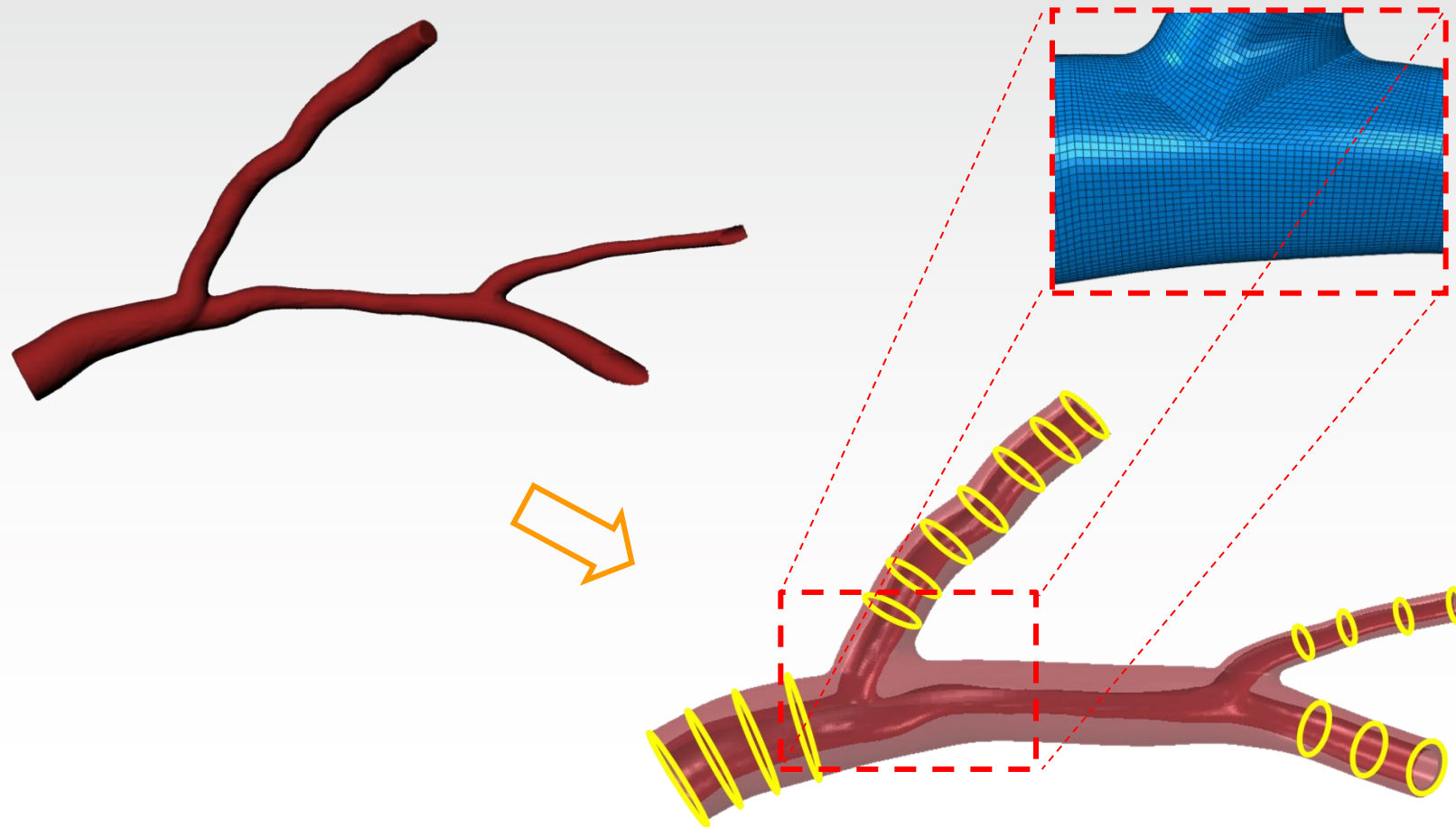
Where we are

Internal surface reconstruction

3D solid model

Discretization

Plaque identification



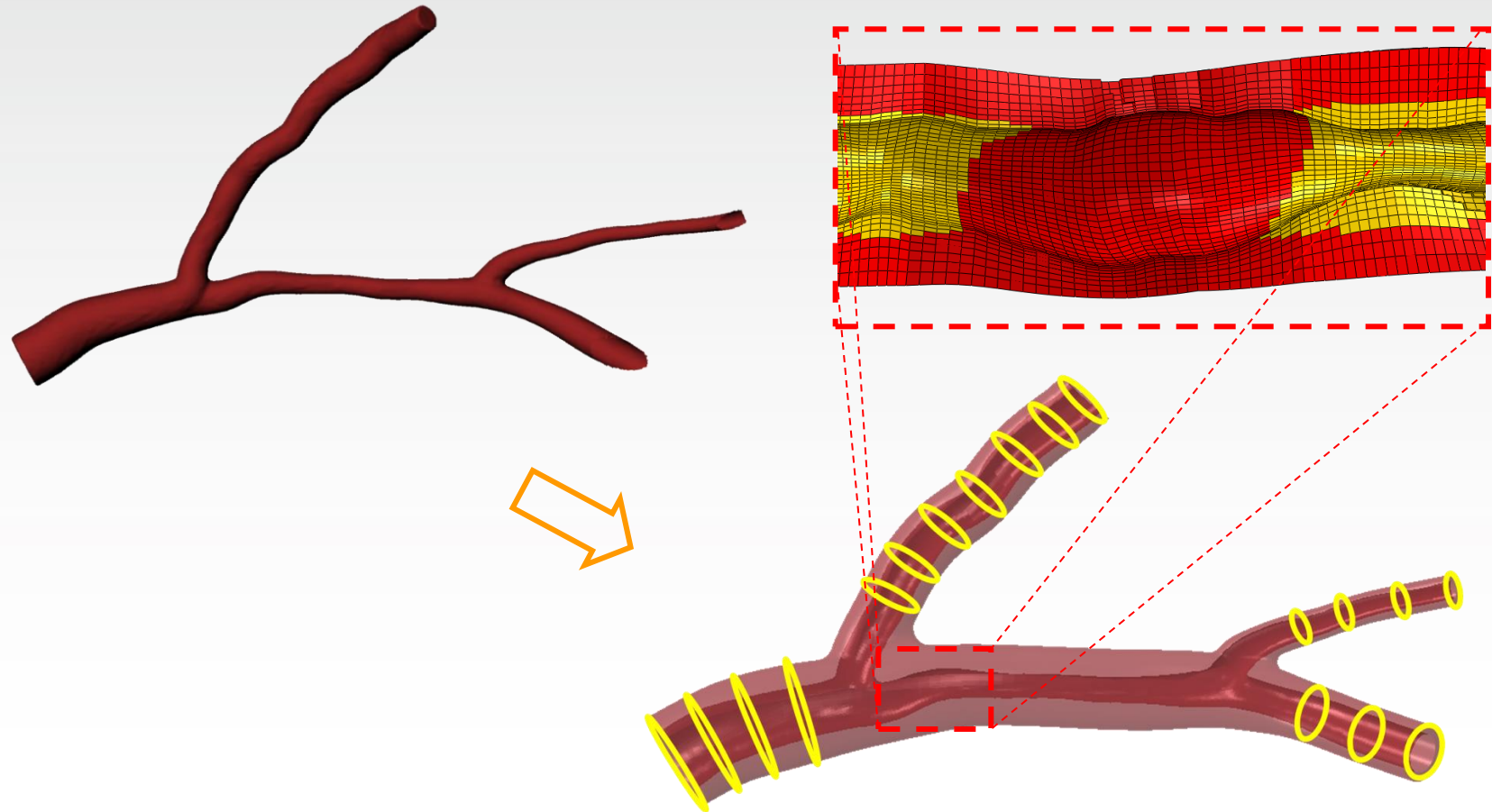
Where we are

Internal surface reconstruction

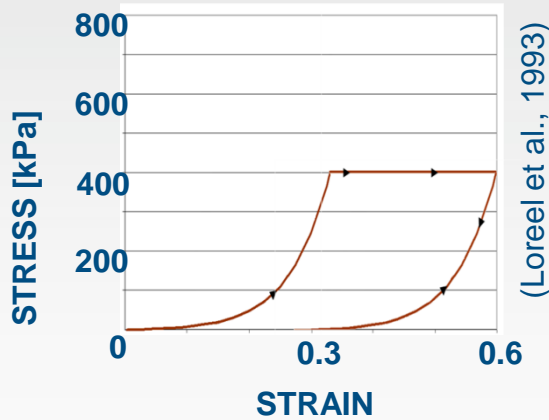
3D solid model

Discretization

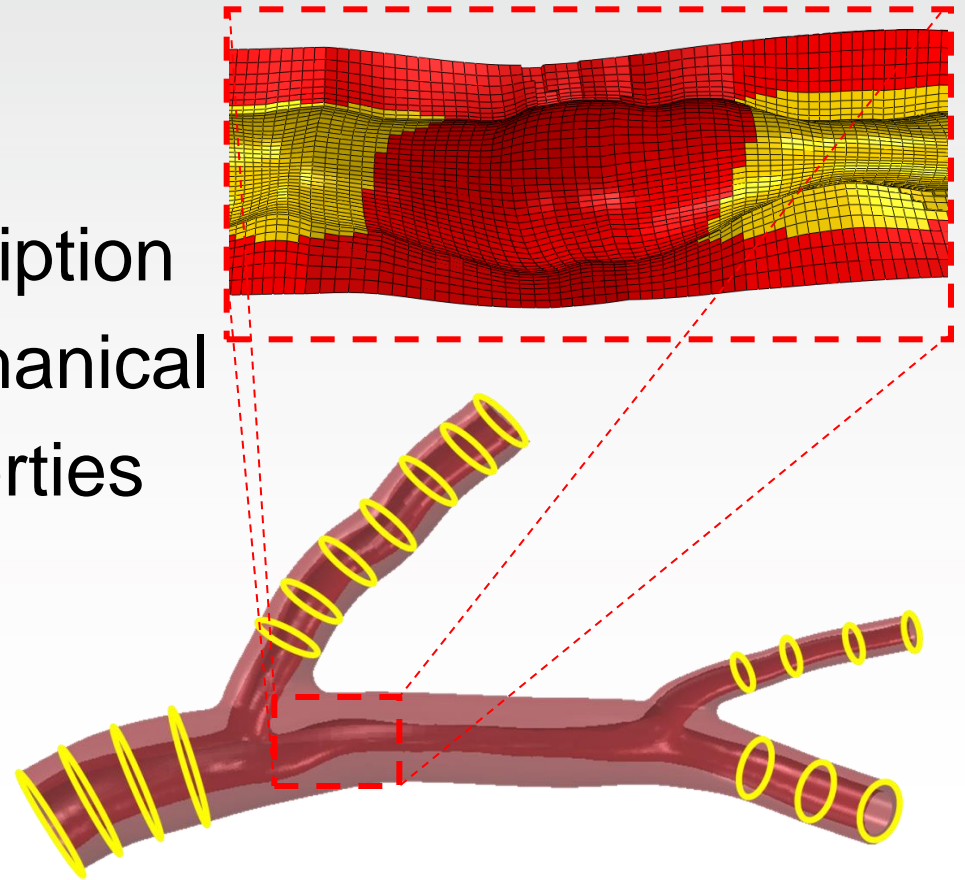
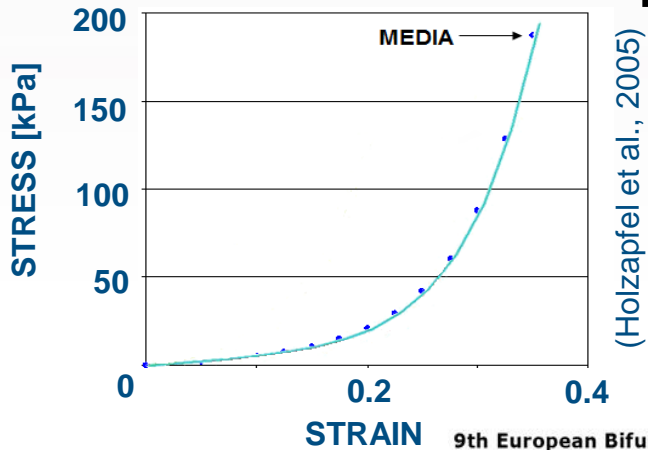
Plaque identification



Where we are



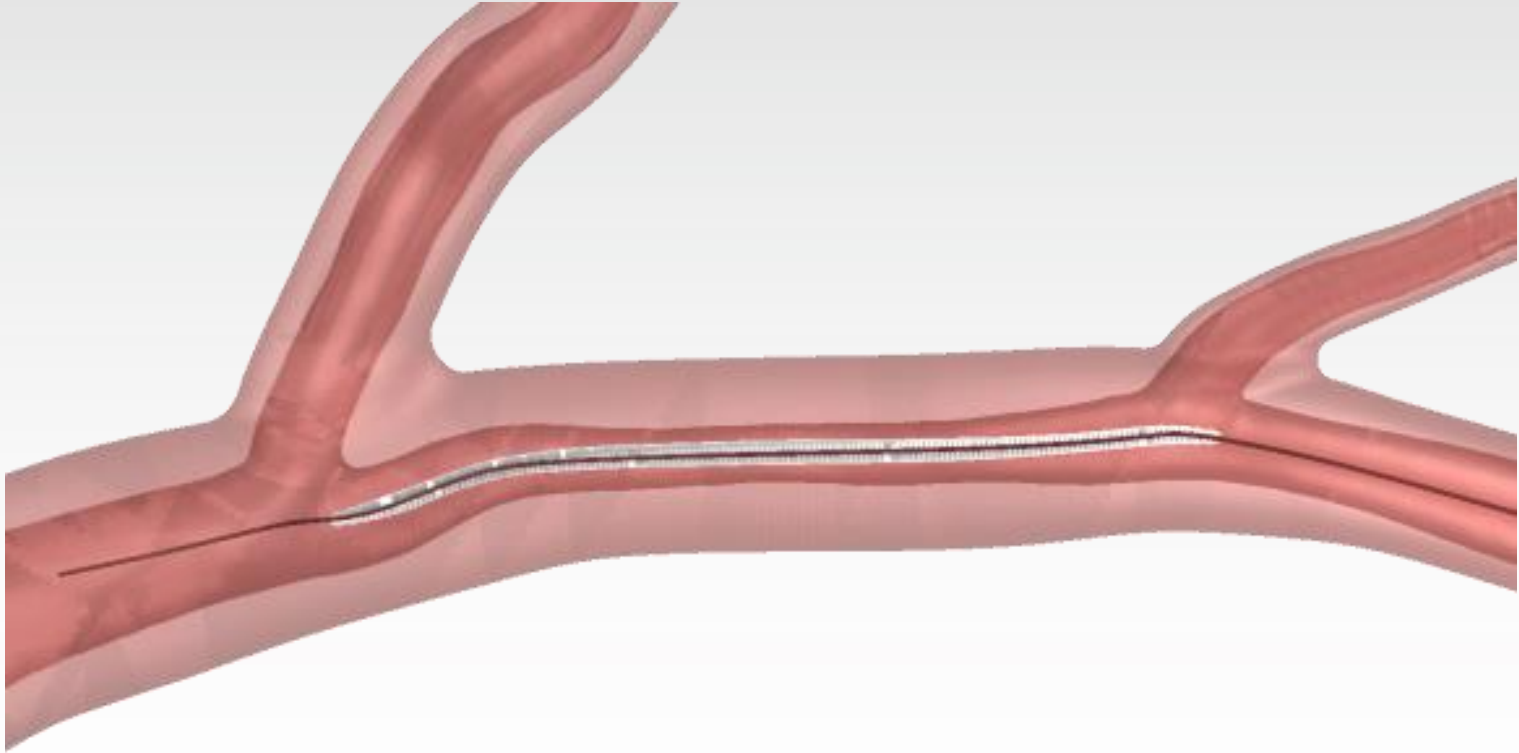
Prescription
of mechanical
properties





Where we are

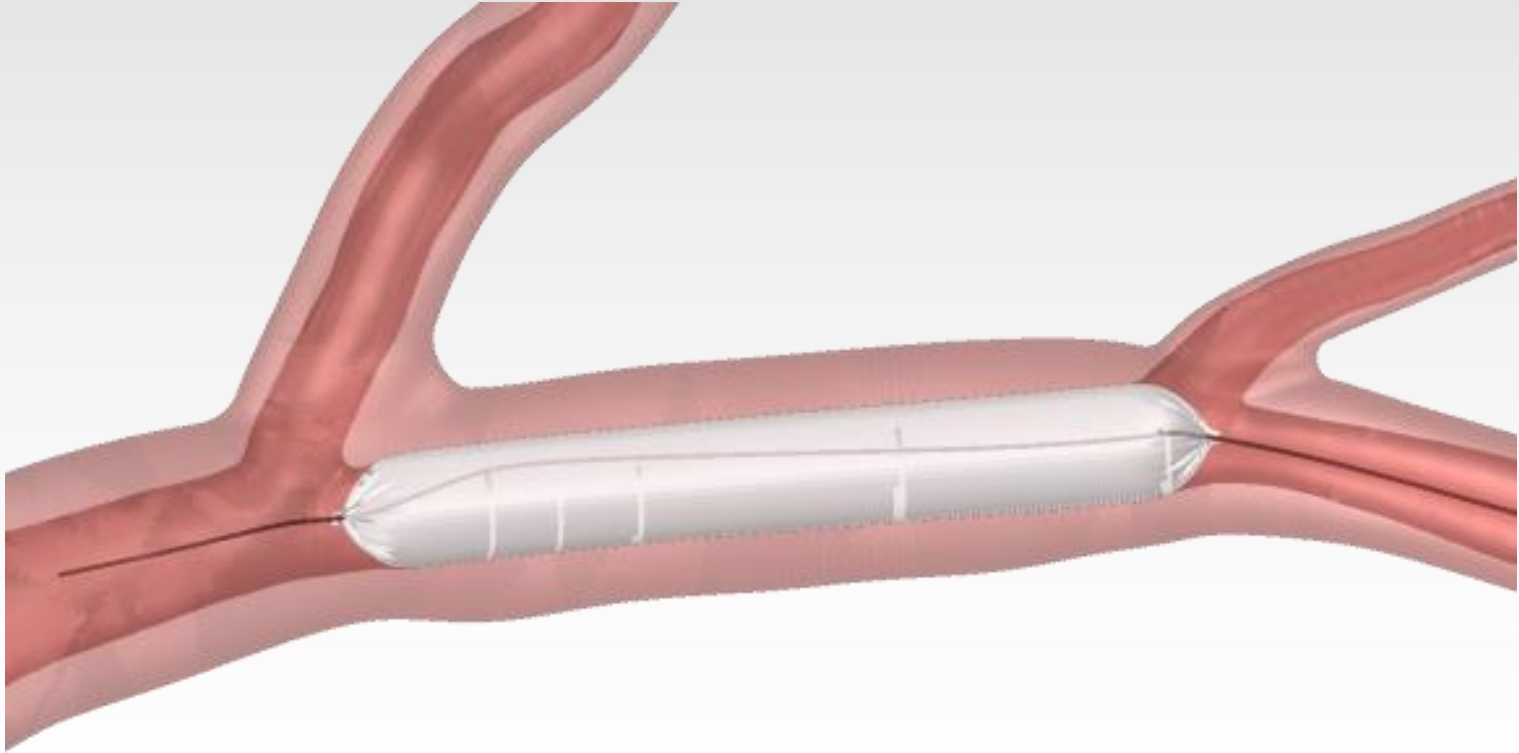
Angioplasty procedure: 15x2 mm balloon





Where we are

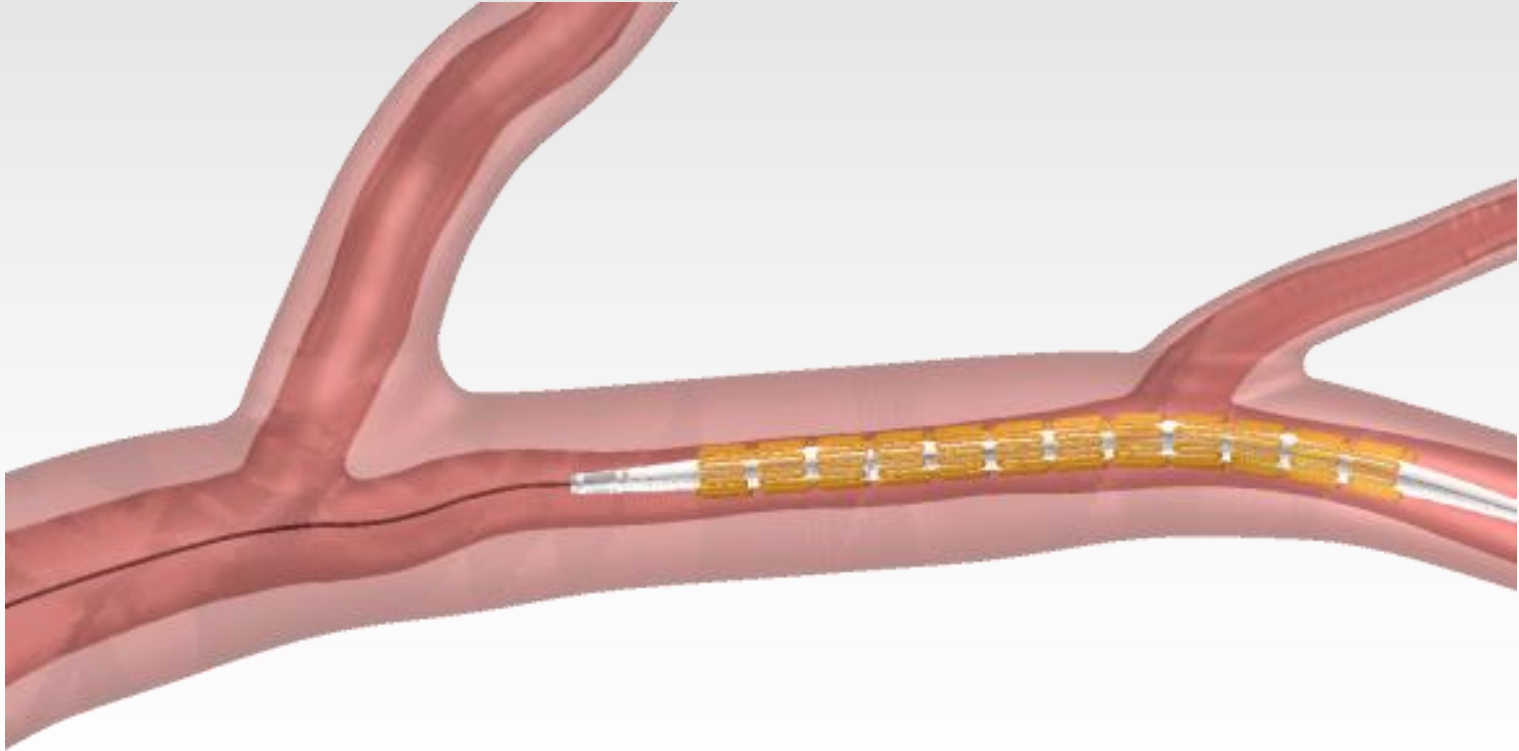
Angioplasty procedure: 15x2 mm balloon





Where we are

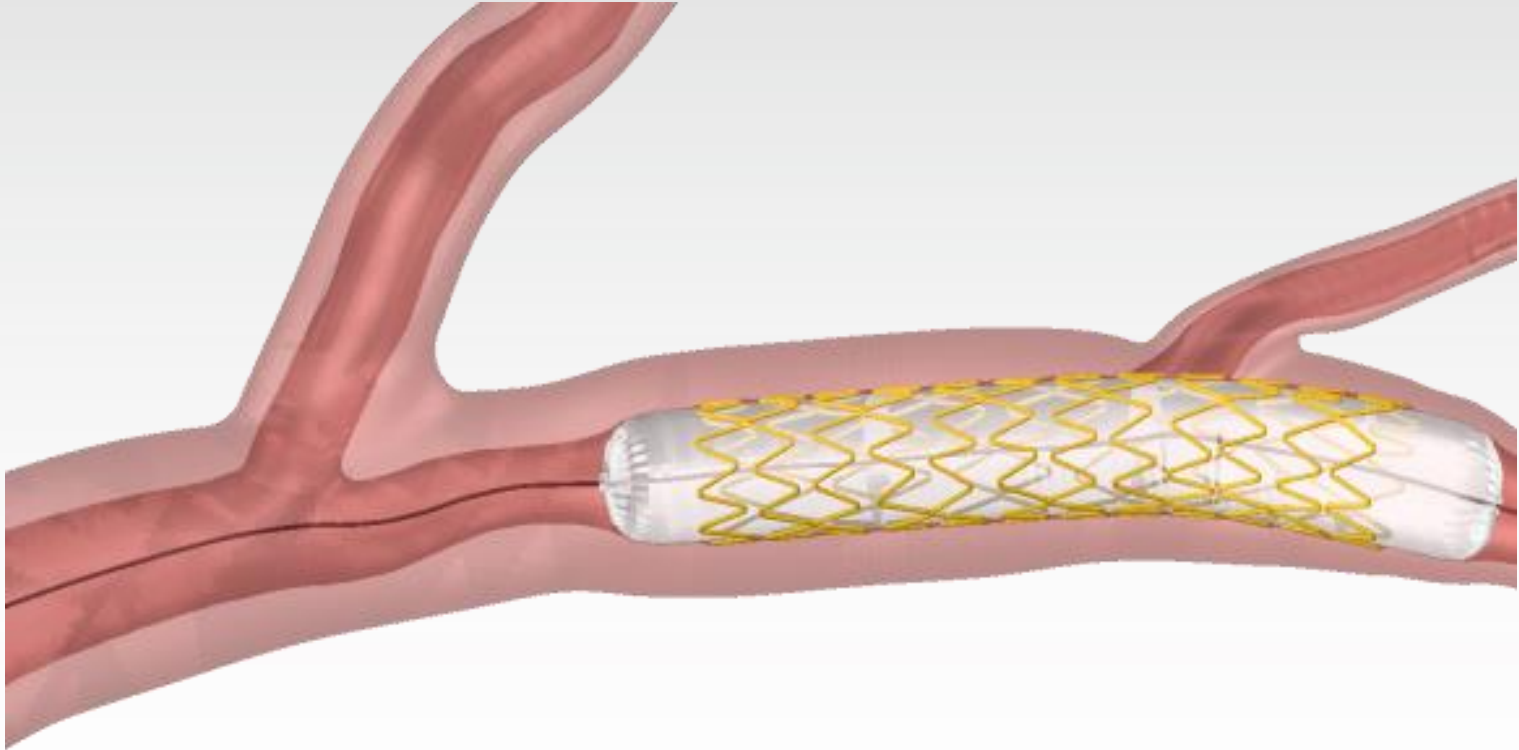
15 mm Endeavor stent deployment: 2.5 mm balloon





Where we are

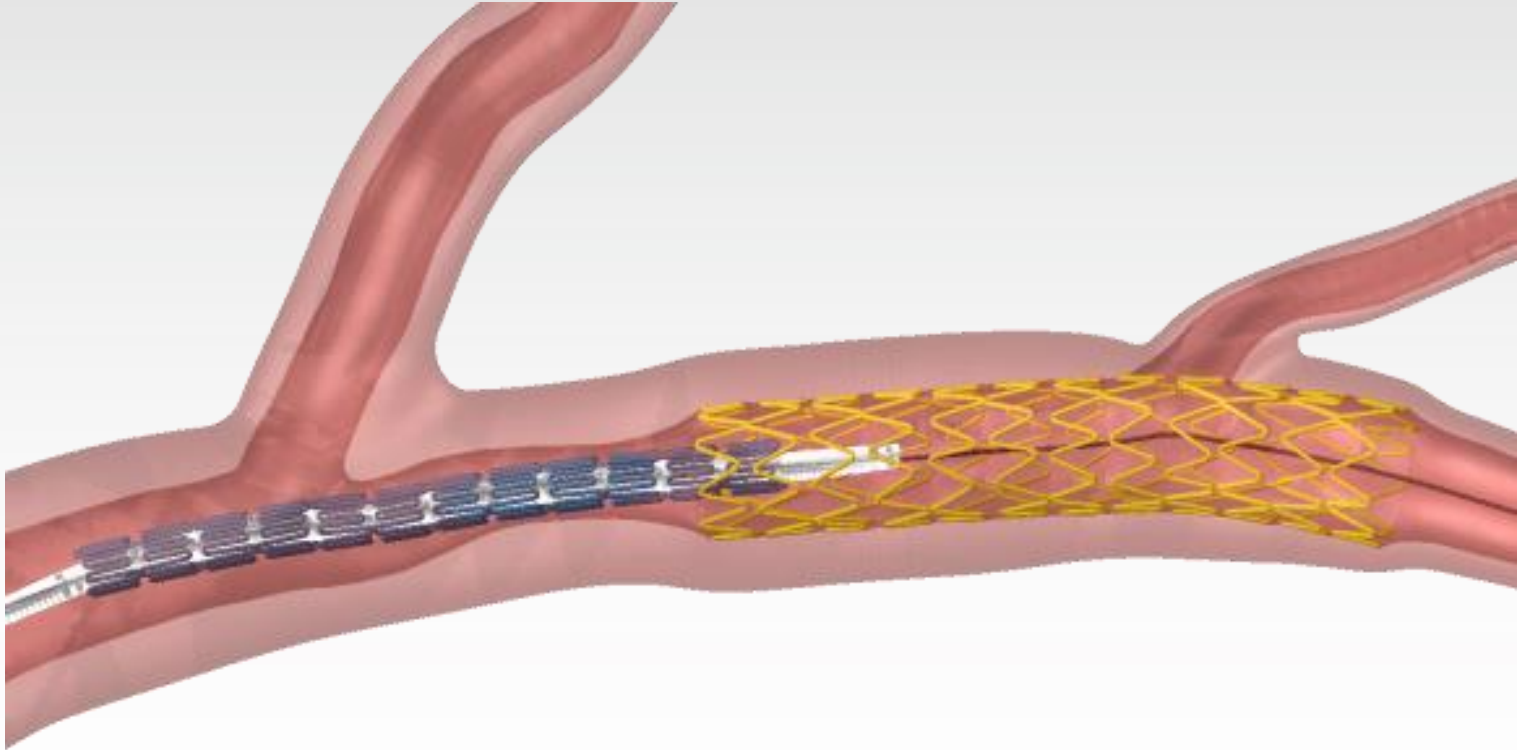
15 mm Endeavor stent deployment: 2.5 mm balloon





Where we are

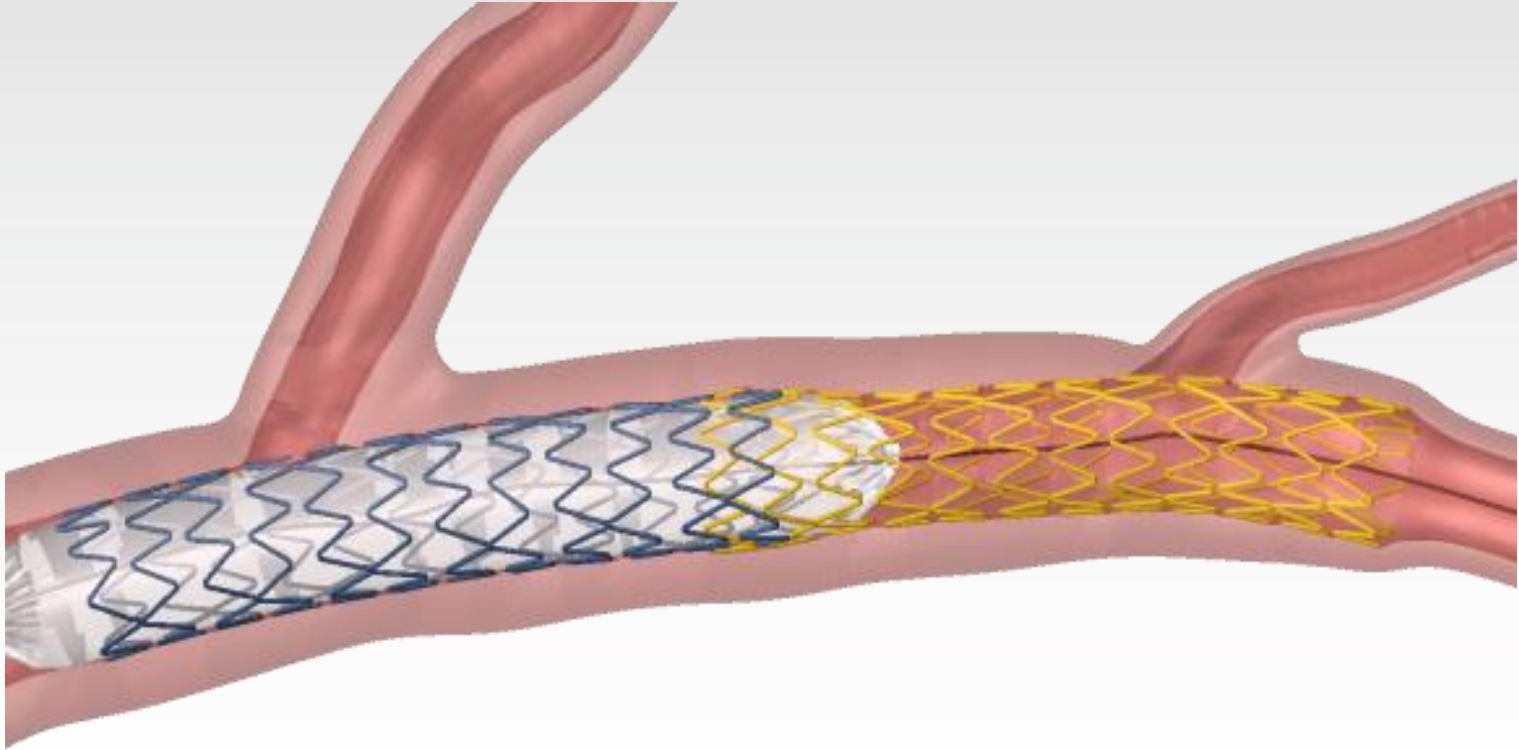
15 mm Endeavor stent deployment: 3 mm balloon





Where we are

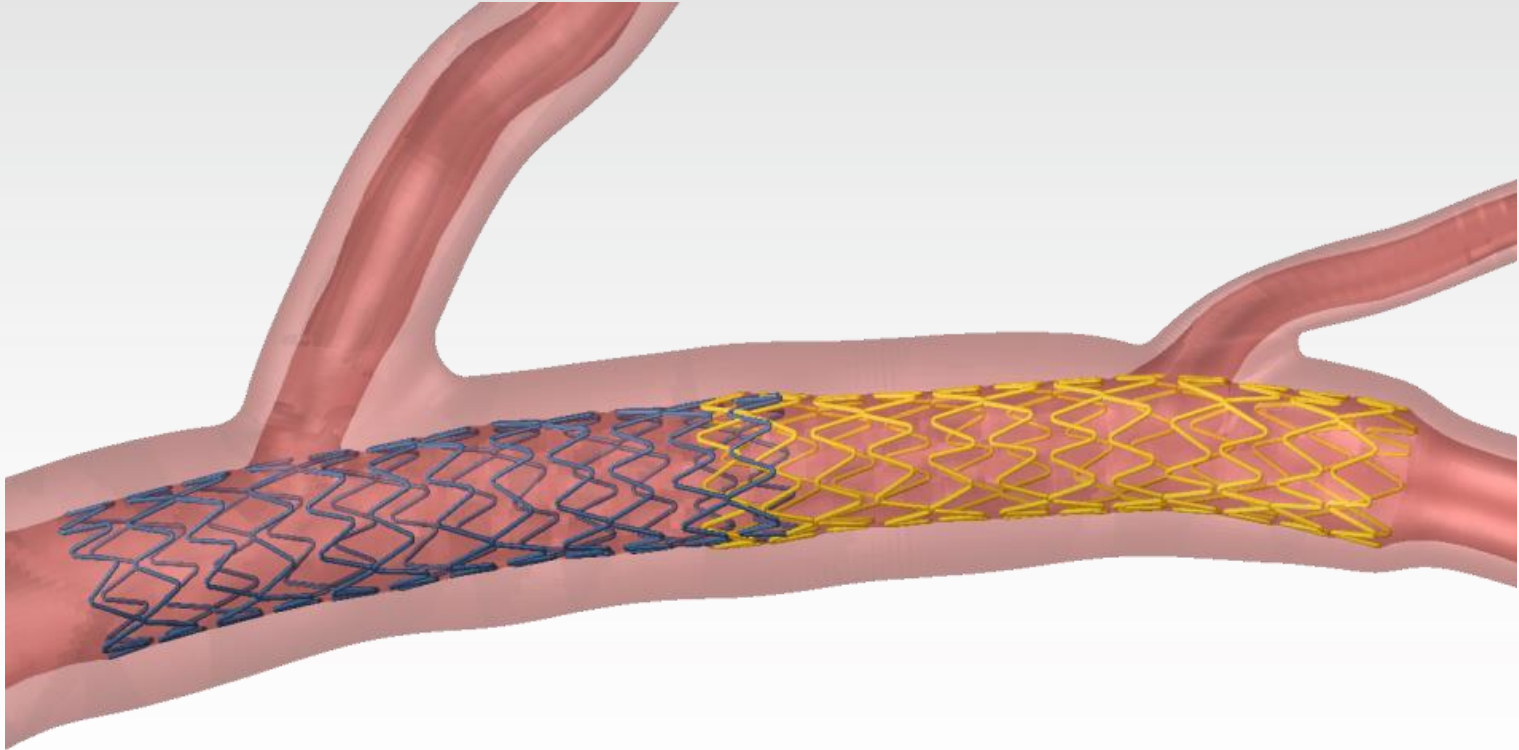
15 mm Endeavor stent deployment: 3 mm balloon





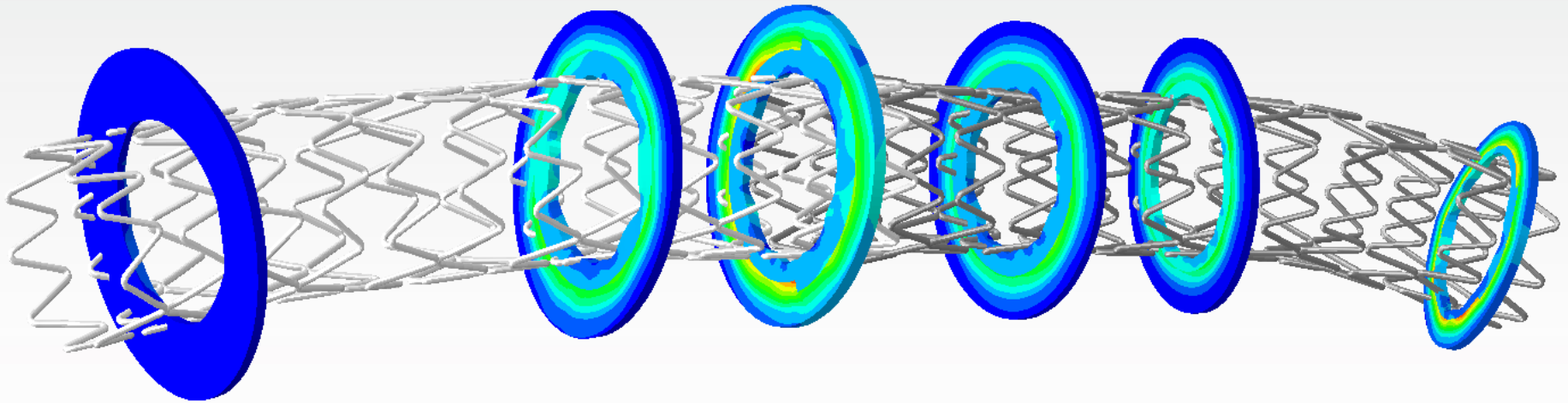
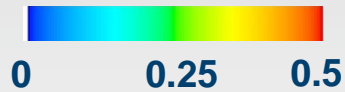
Where we are

Final configuration



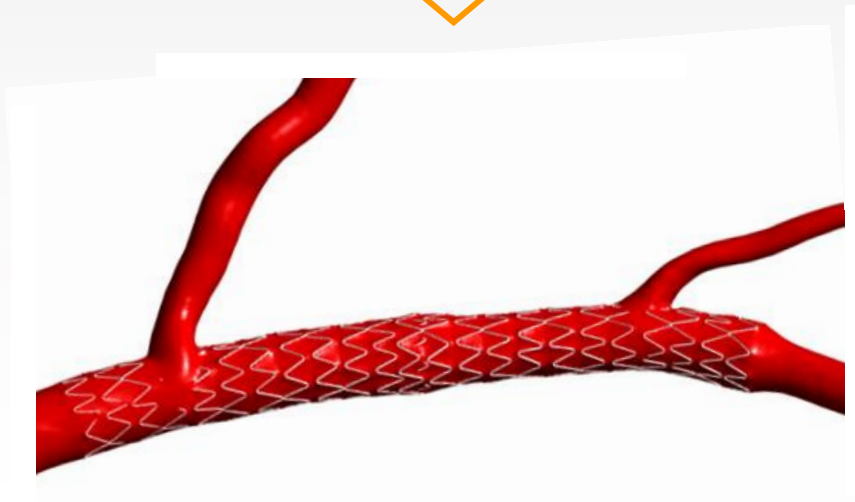
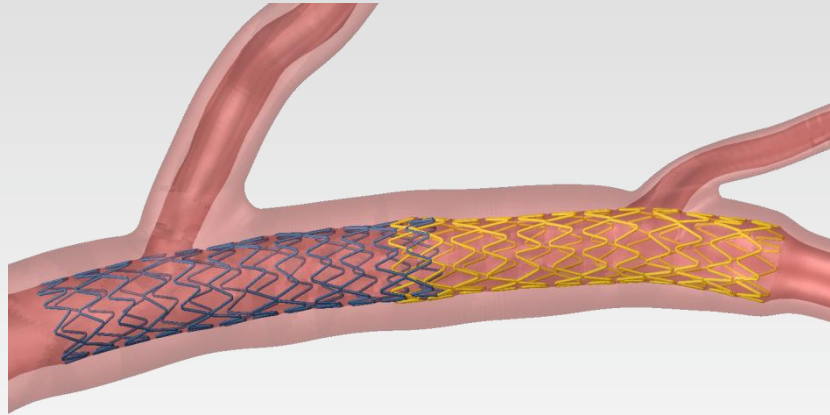
Where we are

Maximum Principal stress [MPa]



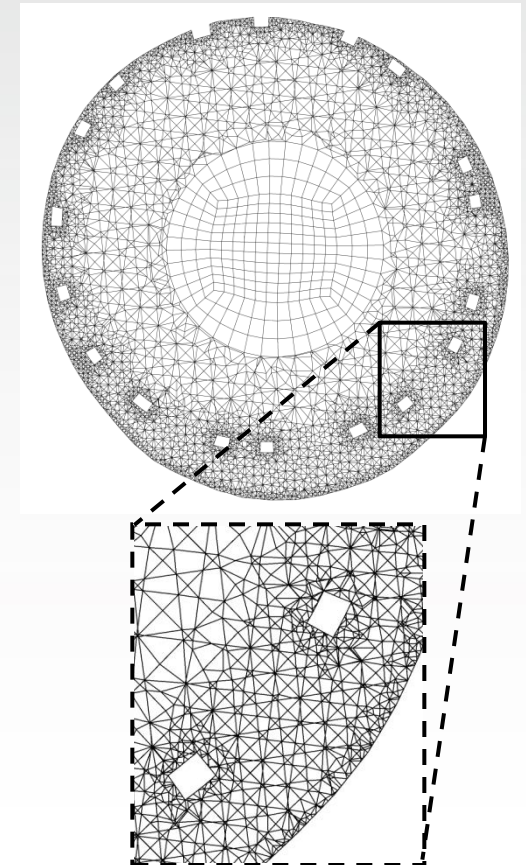
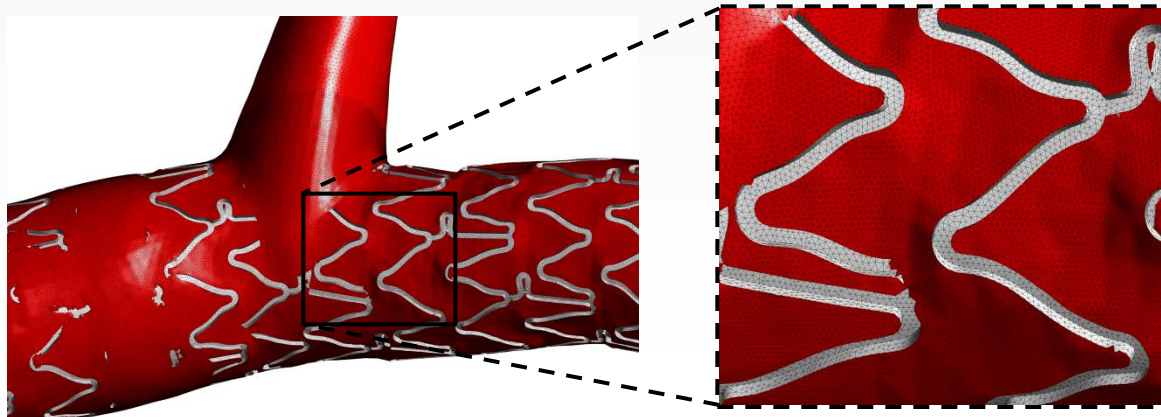
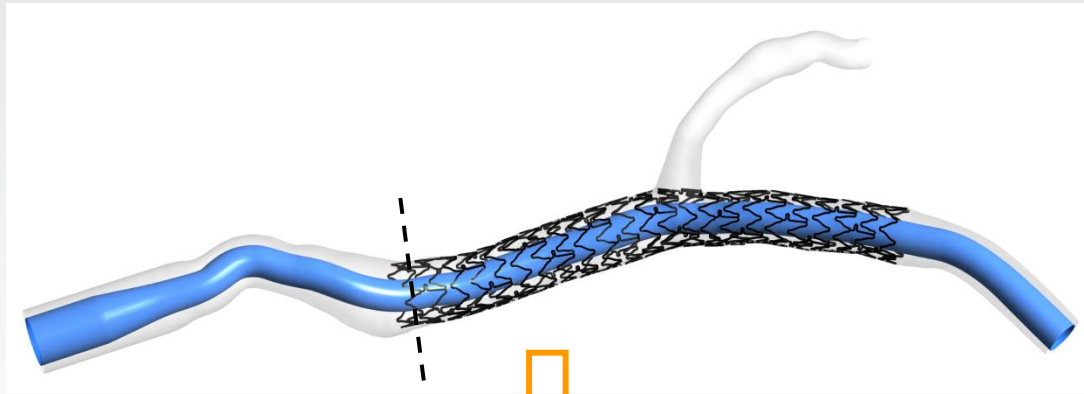
RESIDUAL STRESSES IN THE ARTERIAL WALL

Where we are



From solid mechanics to fluid dynamics

Where we are



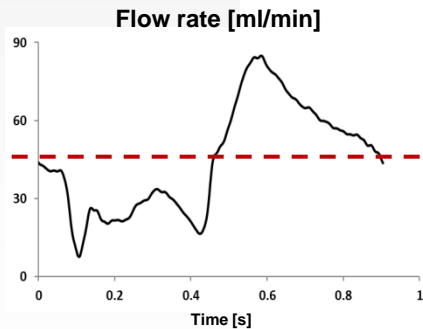
(Chiastra et al. *European J of Mechanics - B/Fluids*, 2012; 35: 76-84)

Where we are



flow rate $q = 1.43 \cdot d^{2.55} \text{ [m}^3/\text{s]}$

flow split $\frac{q_{D2}}{q_{D1}} = \left(\frac{d_{D2}}{d_{D1}}\right)^{2.27}$ (van der Giessen et al. 2011)



(Davies et al. 2006)

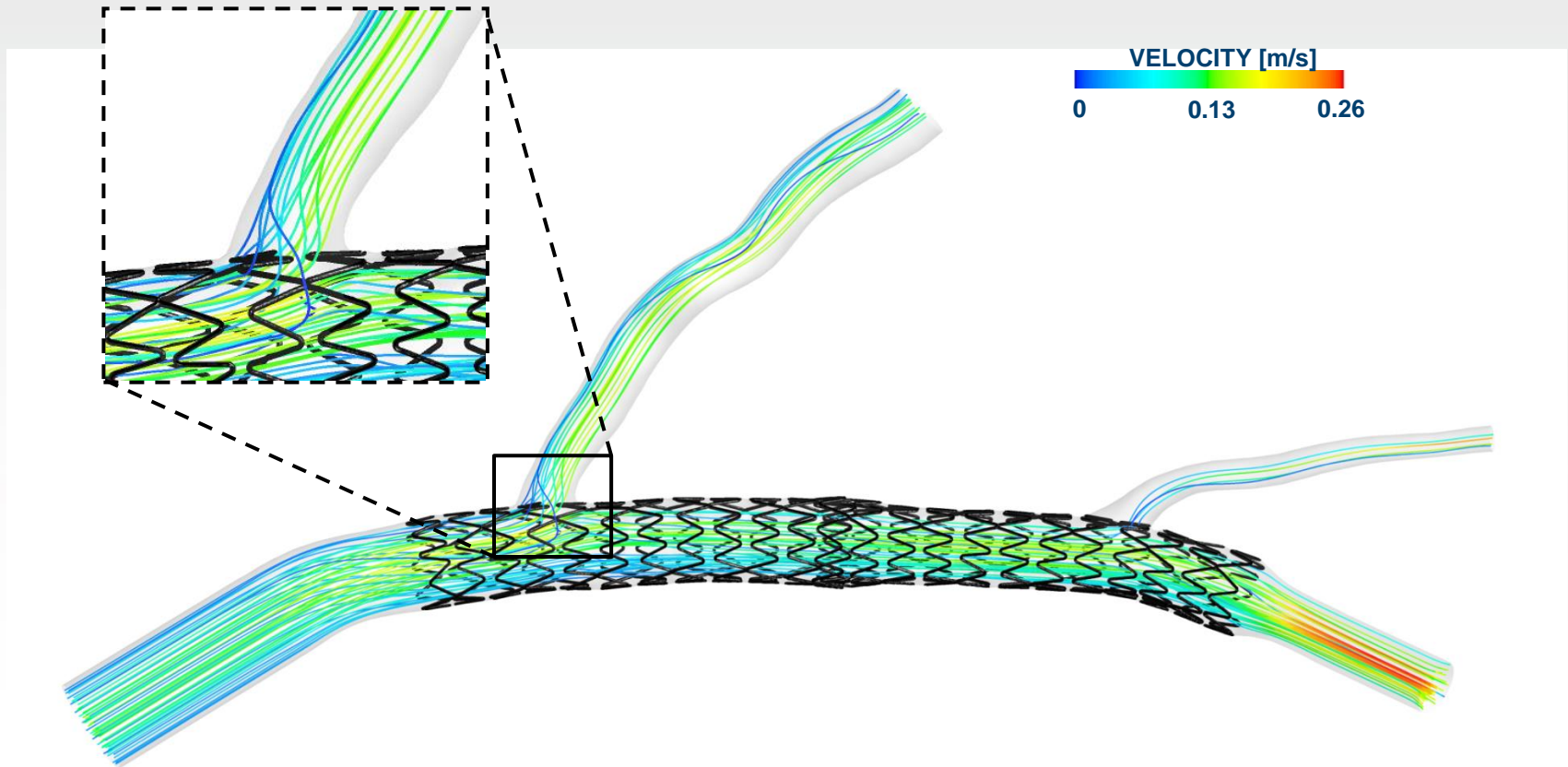
INLET

OUTLET SB 1 (32.9%)

OUTLET SB 2 (9.4%)

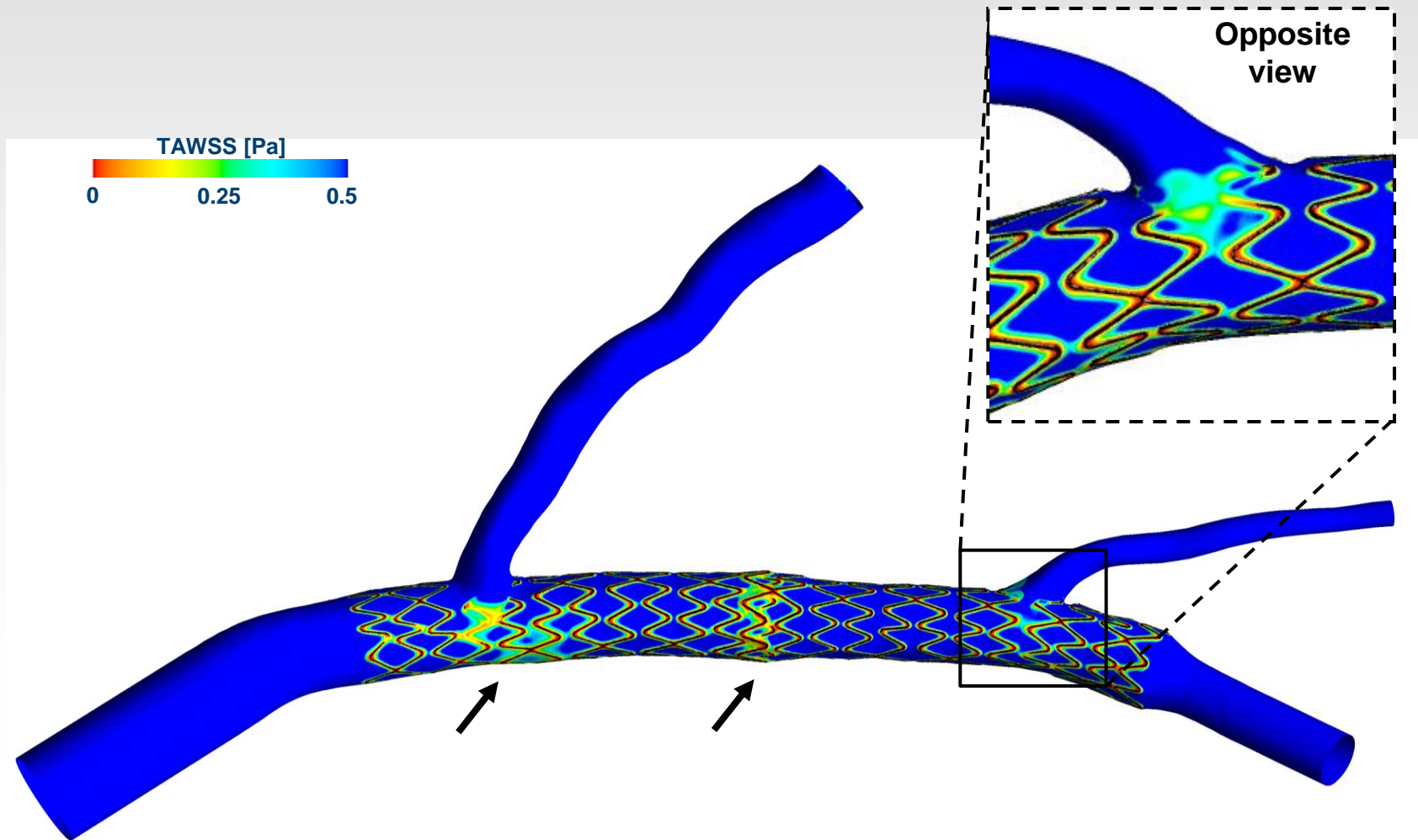
Where we are

Velocity streamlines



Where we are

Time-Averaged Wall Shear Stress (TAWSS)



Assumptions/Limitations

Geometry/anatomy

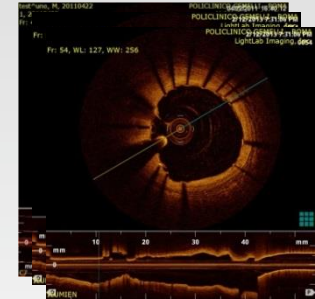
OCT can give better definition
Not a big problem

CA → *centerline*

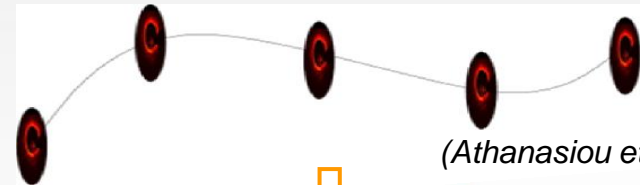


(Policlinico
Gemelli, Rome)

OCT → *vessel and stent*

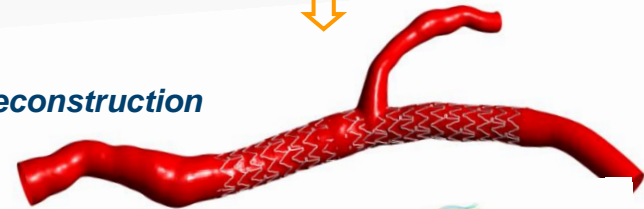


(Policlinico
Gemelli, Rome)



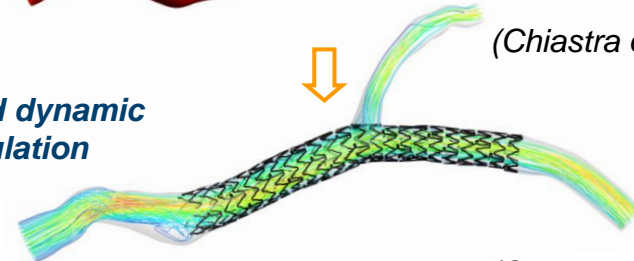
(Athanasίου et al., 2013)

3D reconstruction



(Chiastra et al., 2013)

Fluid dynamic
simulation

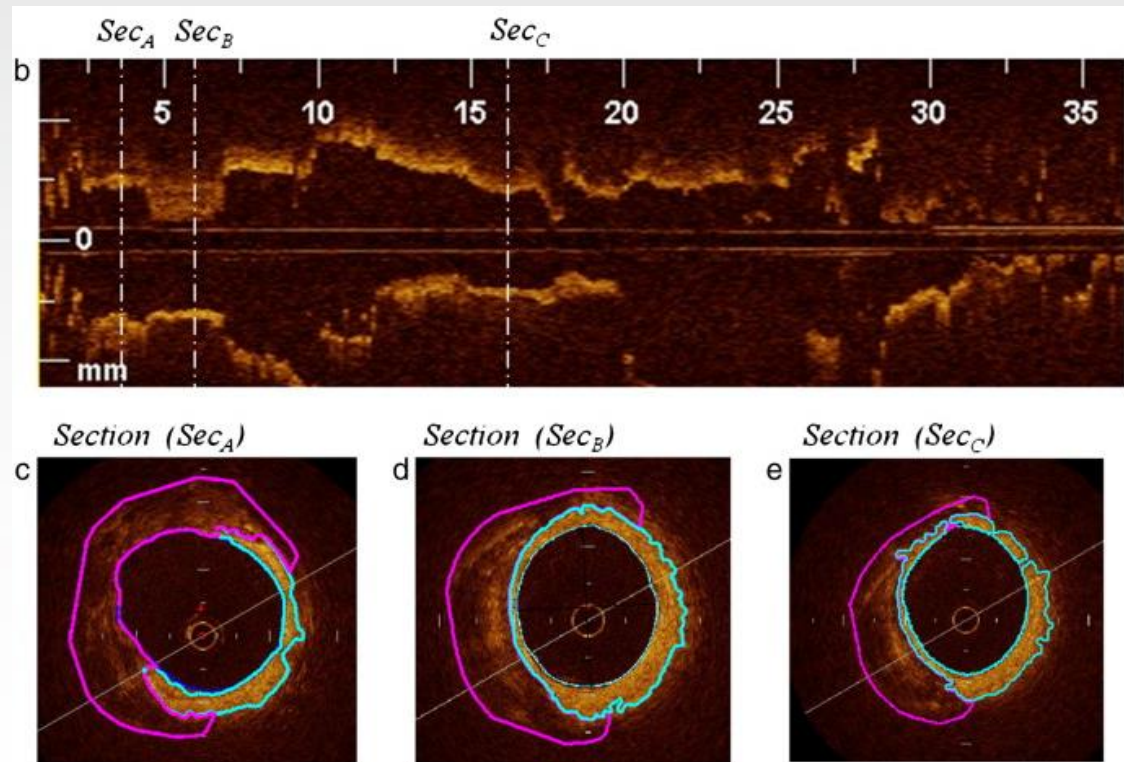


(Chiastra et al., 2013)

Assumptions/Limitations

Geometry/anatomy

Plaque morphology
apparently is a fixed
problem



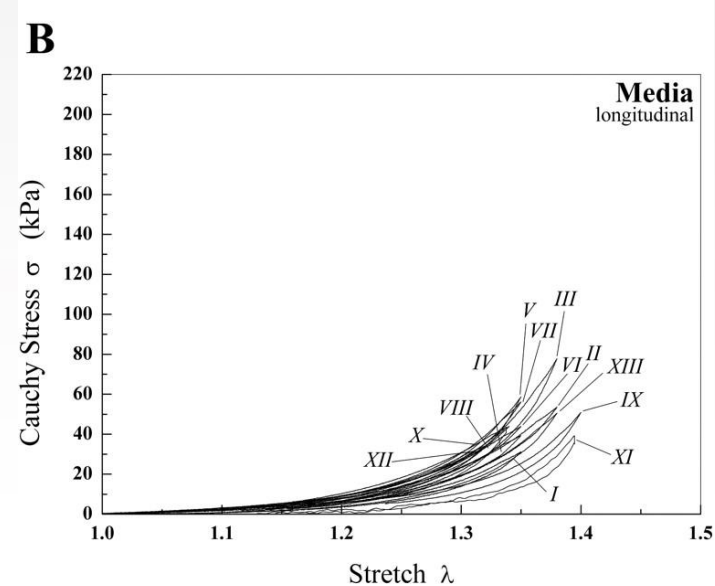
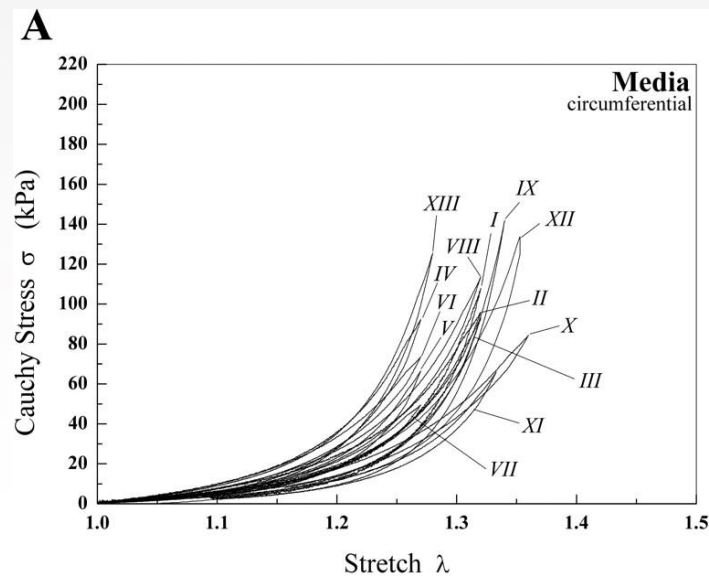
(Celi and Berti, *Int J Cardiol.* 2013)

Assumptions/Limitations

Geometry/anatomy

Vessel and plaque mechanical properties

Not in vivo / not patient-specific!



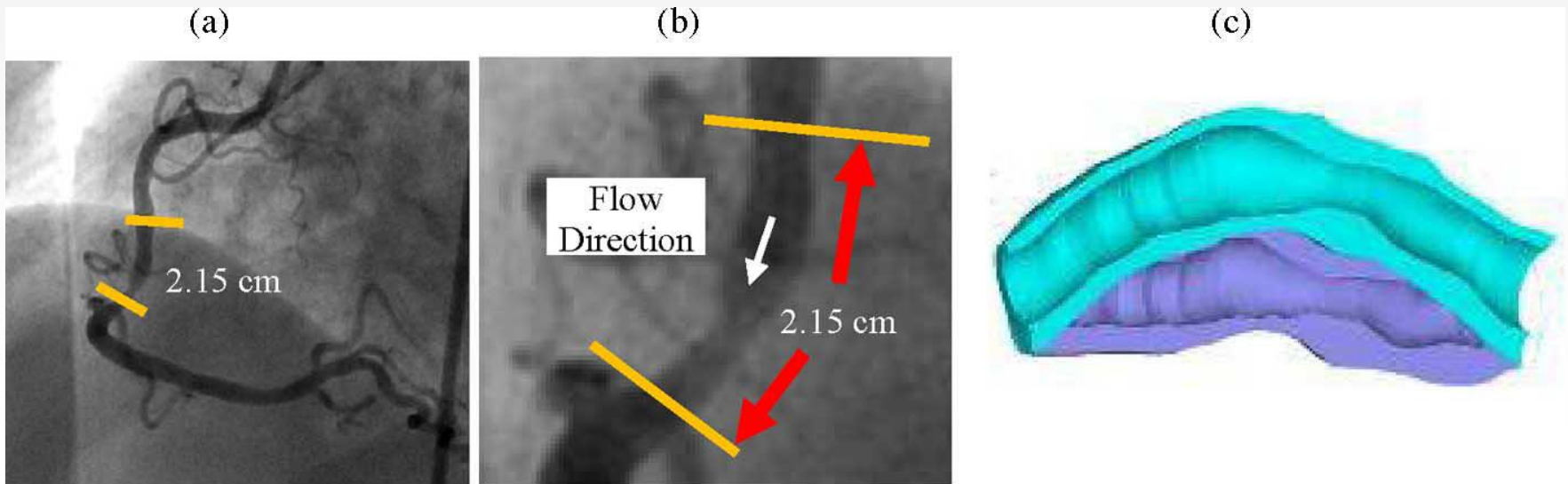
(Holzapfel et al., *Am J Physiol Heart Circ Physiol.* 2005)

Assumptions/Limitations

Geometry/anatomy

Vessel and plaque mechanical properties

Surrounding tissue: motion



(Yang et al., *IEEE Biomed. Trans.*, 2009)

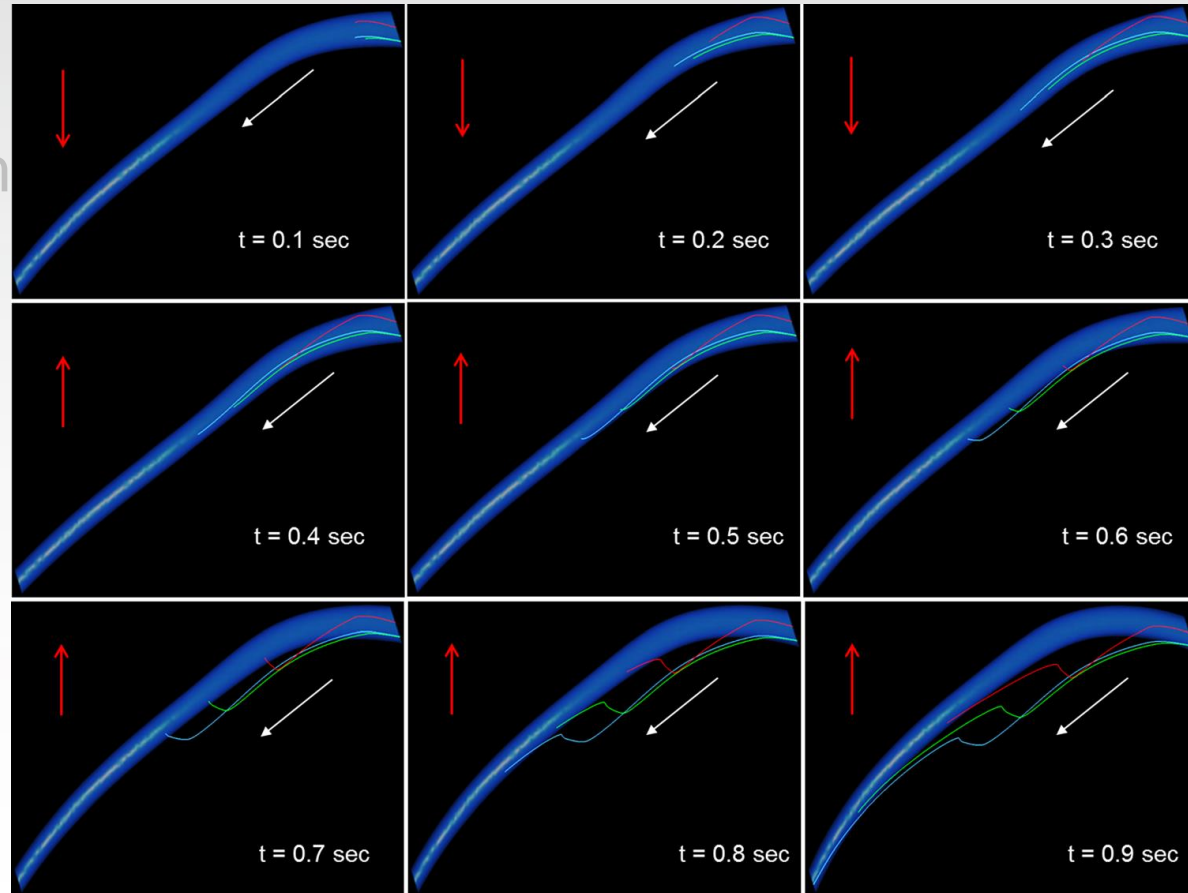
Assumptions/Limitations

Geometry/anatomy

Vessel and plaque m

Surrounding tissue:
motion

Minor effects on
local fluid dynamics



(Hasa et al., ASME J. Biomech. Engng., 2013)



Assumptions/Limitations

Geometry/anatomy

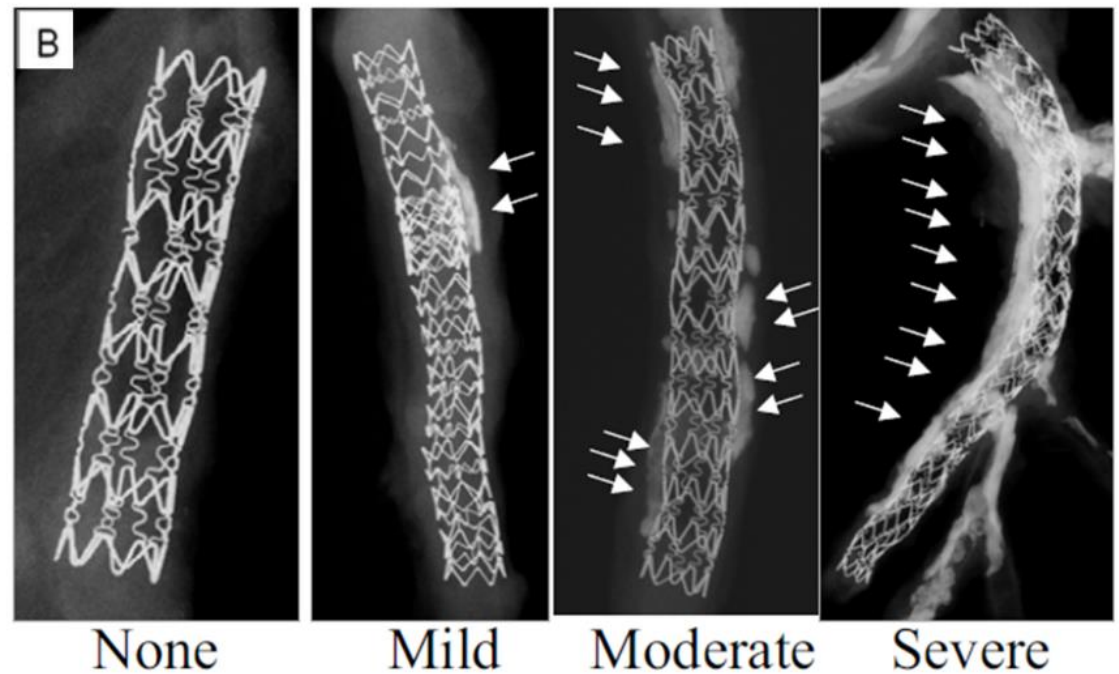
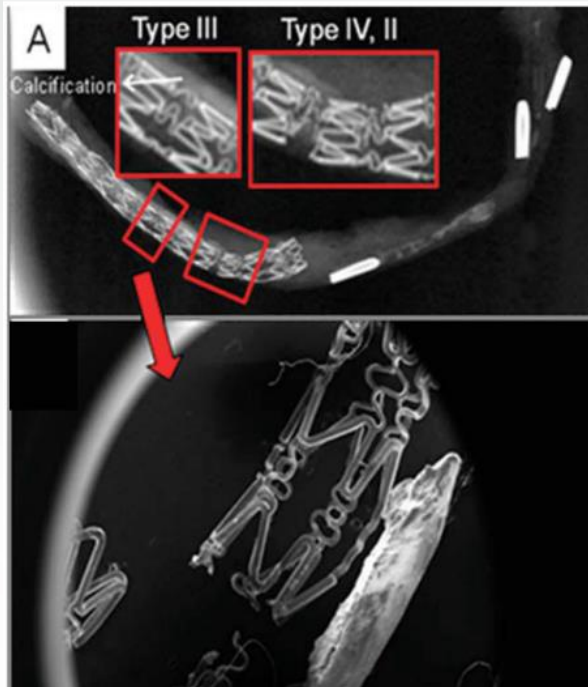
Vessel and plaque mechanical properties

Surrounding tissue: motion

Important for stent fatigue life and risk of fracture!

Assumptions/Limitations

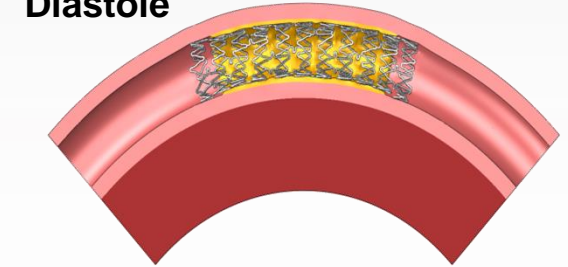
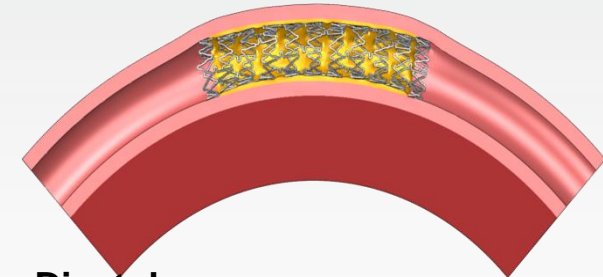
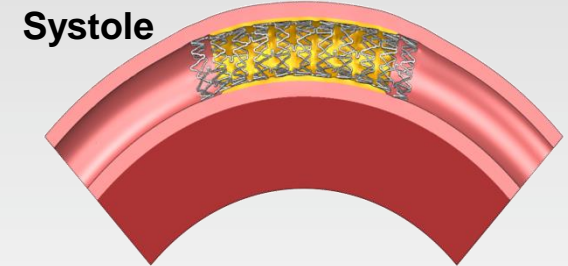
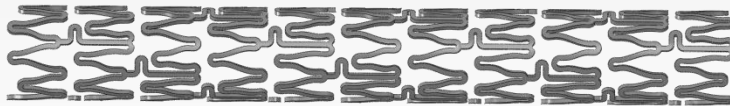
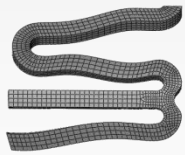
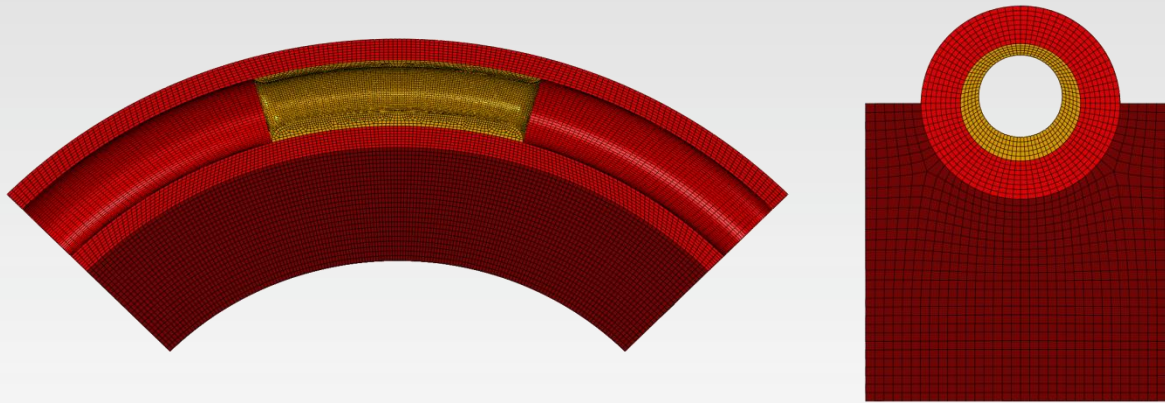
Stent fatigue life and risk of fracture



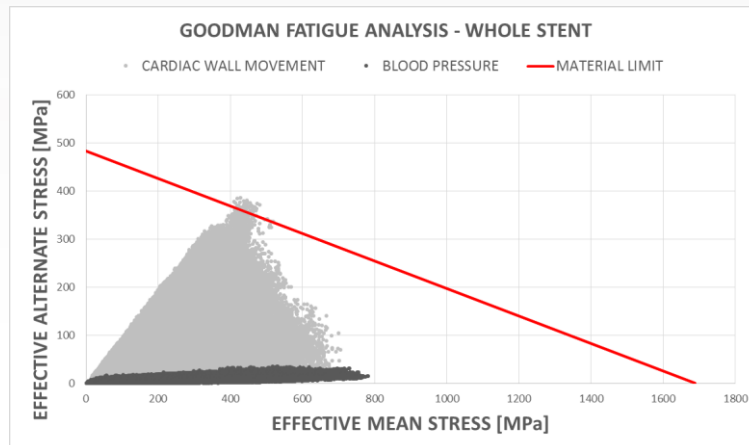
(Nakazawa et al. J Am Coll Cardiol. 2009)

Assumptions/Limitations

Stent fatigue life and risk of fracture



Systole





Assumptions/Limitations

Geometry/anatomy

Vessel and plaque mechanical properties

Surrounding tissue: motion

Flow boundary conditions

Need for measuring patient-specific flows!
This is important for WSS estimation and correlation with post-operative ISR.

Conclusions

Geometry/anatomy



Vessel and plaque mechanical properties



Surrounding tissue: motion



Flow boundary conditions



Temporal evolution





Acknowledgements

Politecnico di Milano, Milan

Prof. Francesco Migliavacca

Mr. Claudio Chiastra

Dr. Stefano Morlacchi (now with the University of Sheffield)

Pompeu Fabra University, Barcelona

Dr. Ignacio Larrabide

Dr. Ruben Cárdenes