Process or principles of patient-specific fluid dynamics simulations

Claudio Chiastra

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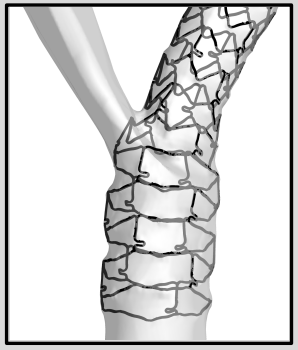
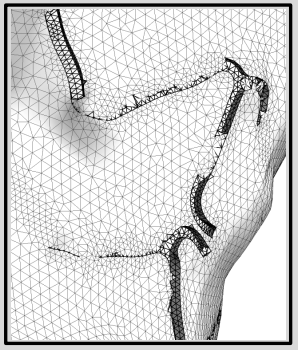
Fluid dynamics simulations: workflow

Geometry



Meshing



Analysis setup

- **Physical model (governing equations)**

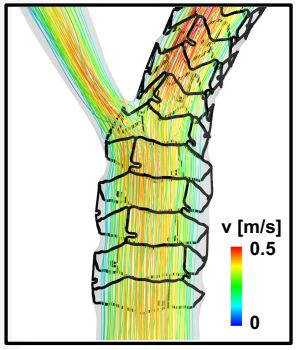
$$\rho\frac{\partial \mathbf{v}}{\partial t} + \rho(\mathbf{v}\cdot\nabla\mathbf{v})\mathbf{v} = -\nabla p + \mu\nabla^2\mathbf{v} + \mathbf{f}^B$$

$$\frac{\partial \rho}{\partial t} + \nabla\cdot(\rho\mathbf{v}) = 0$$

- **Fluid properties**
- **Boundary conditions**
- **Solver settings**

Solving

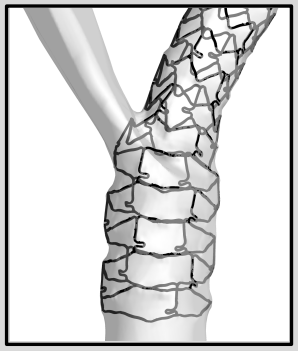
Post-processing



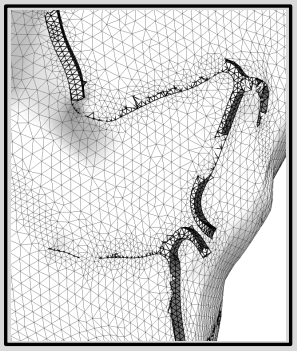
Fluid dynamics simulations: workflow

PATIENT-SPECIFIC ANALYSIS

Geometry



Meshing



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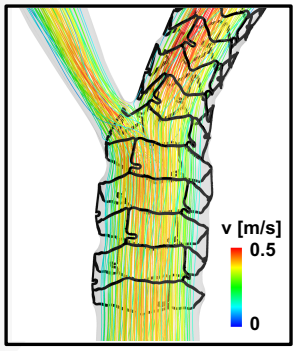
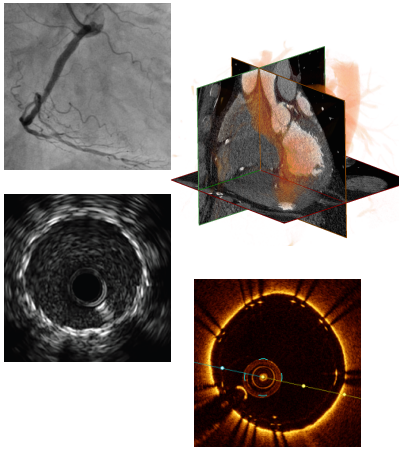


Patient's imaging data

- Angiography
  - CT
- IVUS
  - OCT

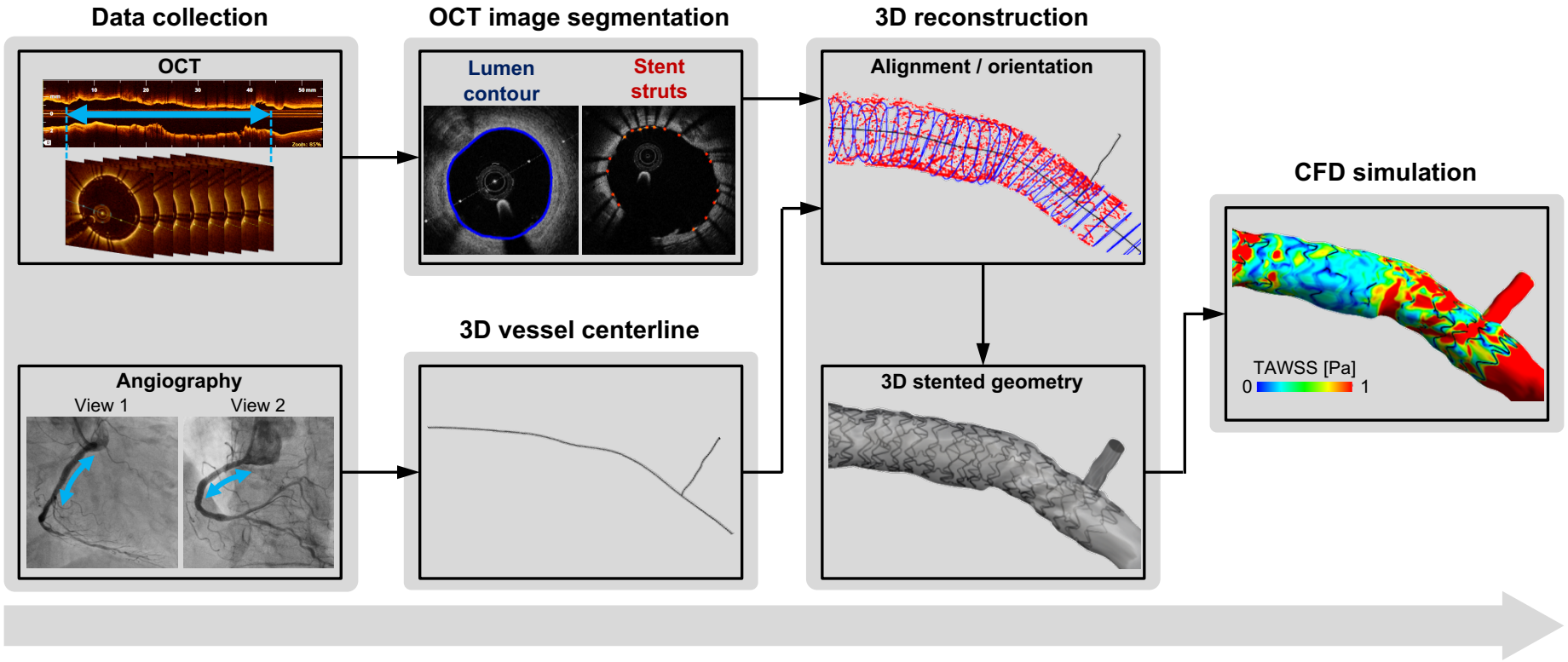


Patient-specific boundary conditions

- HR
- Velocity / flow-rate (Doppler, frame count method)
- Pressure

Patient-specific modeling: our approach

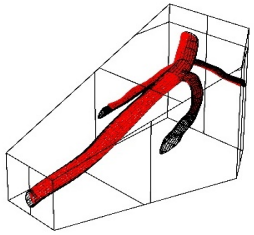
Development of a **semi-automatic method** for the **reconstruction** of **patient-specific stented coronary arteries** from **OCT** images for **fluid dynamics** analyses



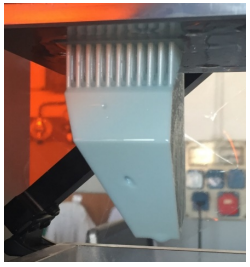
Chiastra et al. *J Cardiovasc Transl Res*, Under Review

Validation of the reconstruction method

Geometrical model

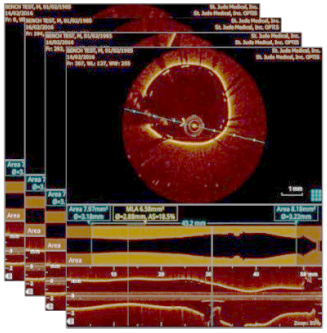


3D printing



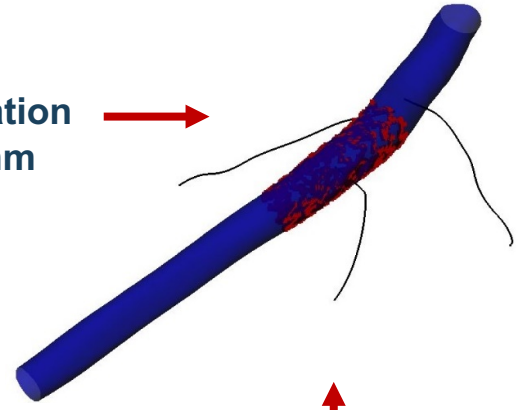
Stent deployment

OCT Images



OCT segmentation algorithm

3D reconstruction method



Validation

μCT scan

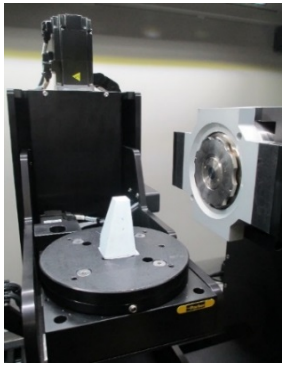
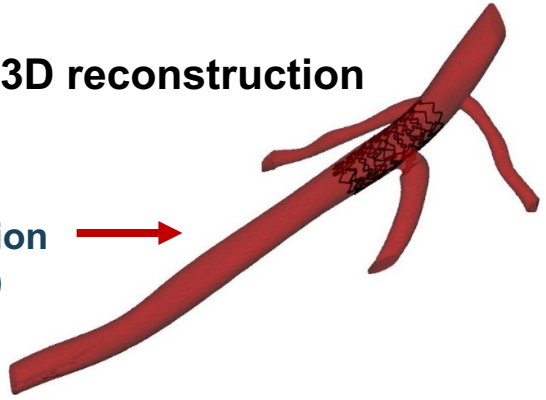


Image segmentation (Mimics)

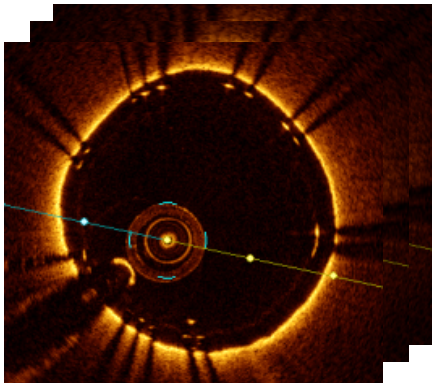
3D reconstruction



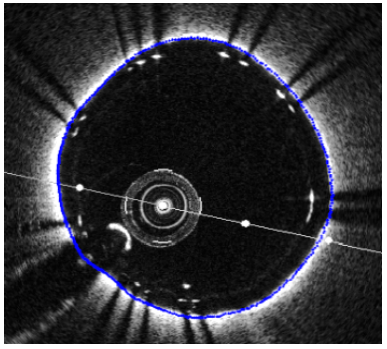
Migliori, Chiastra et al. *Med Eng Phys*, 2017

3D reconstruction method

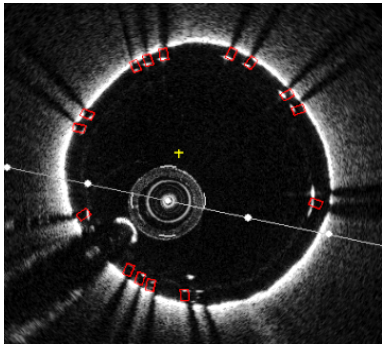
OCT Images

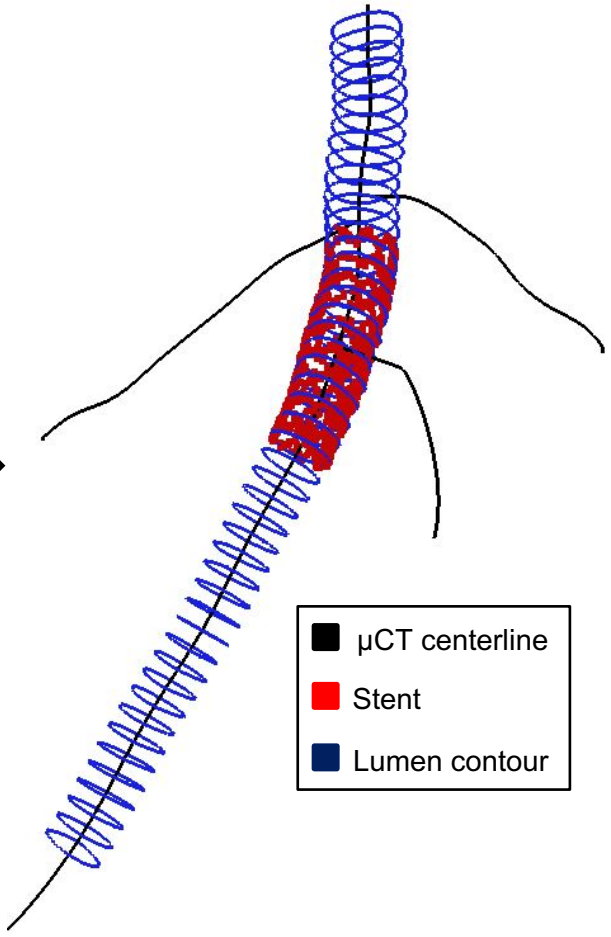


Lumen contour



Stent struts

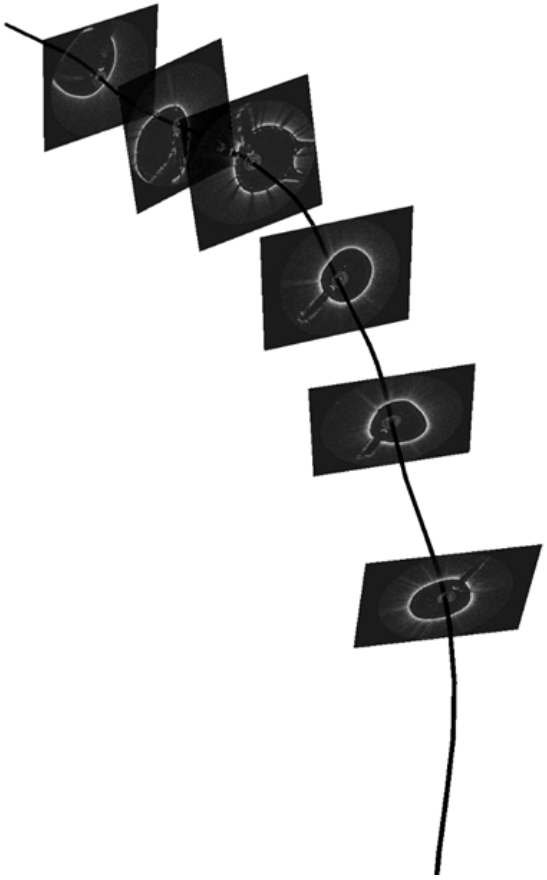




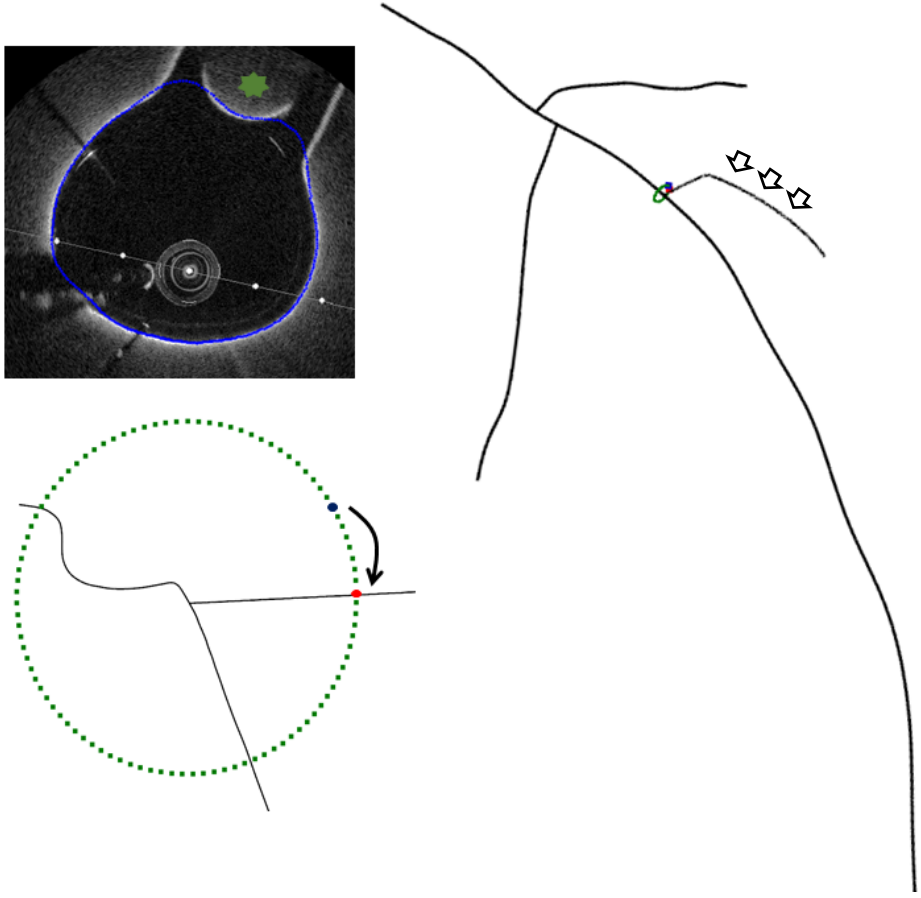
For details on the **detection algorithms** see: **Chiastra et al. *PLoS ONE,* 2017**
Migliori et al. *Med Eng Phys,* 2017

OCT frames alignment / rotation

- **Alignment** of lumen contours and stent struts along the main branch centerline

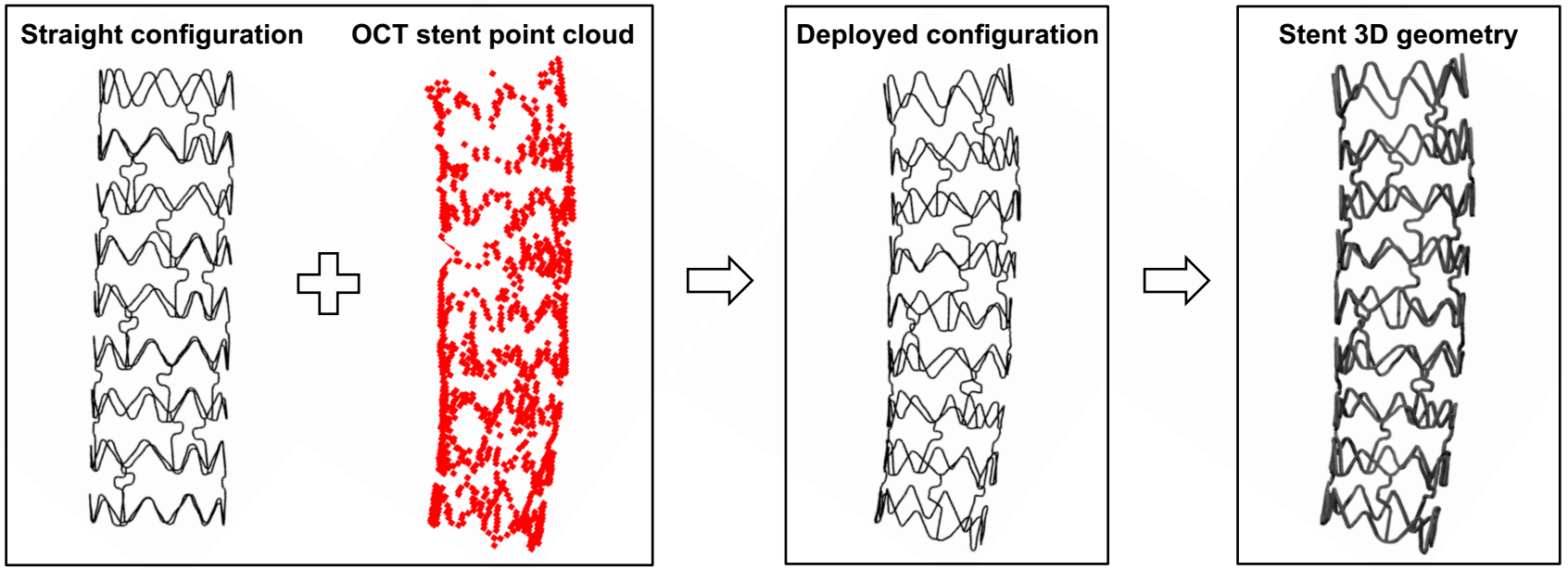


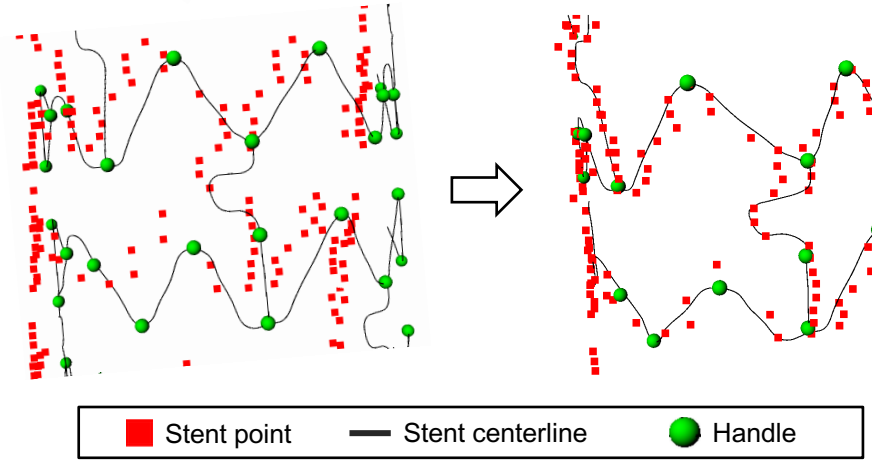
- **Twist angle error estimation** through the side branch centerline

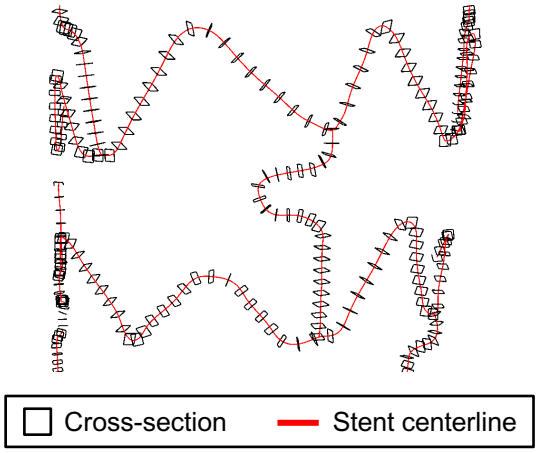


Migliori, Chiastra et al. *Med Eng Phys*, 2017

Stent reconstruction



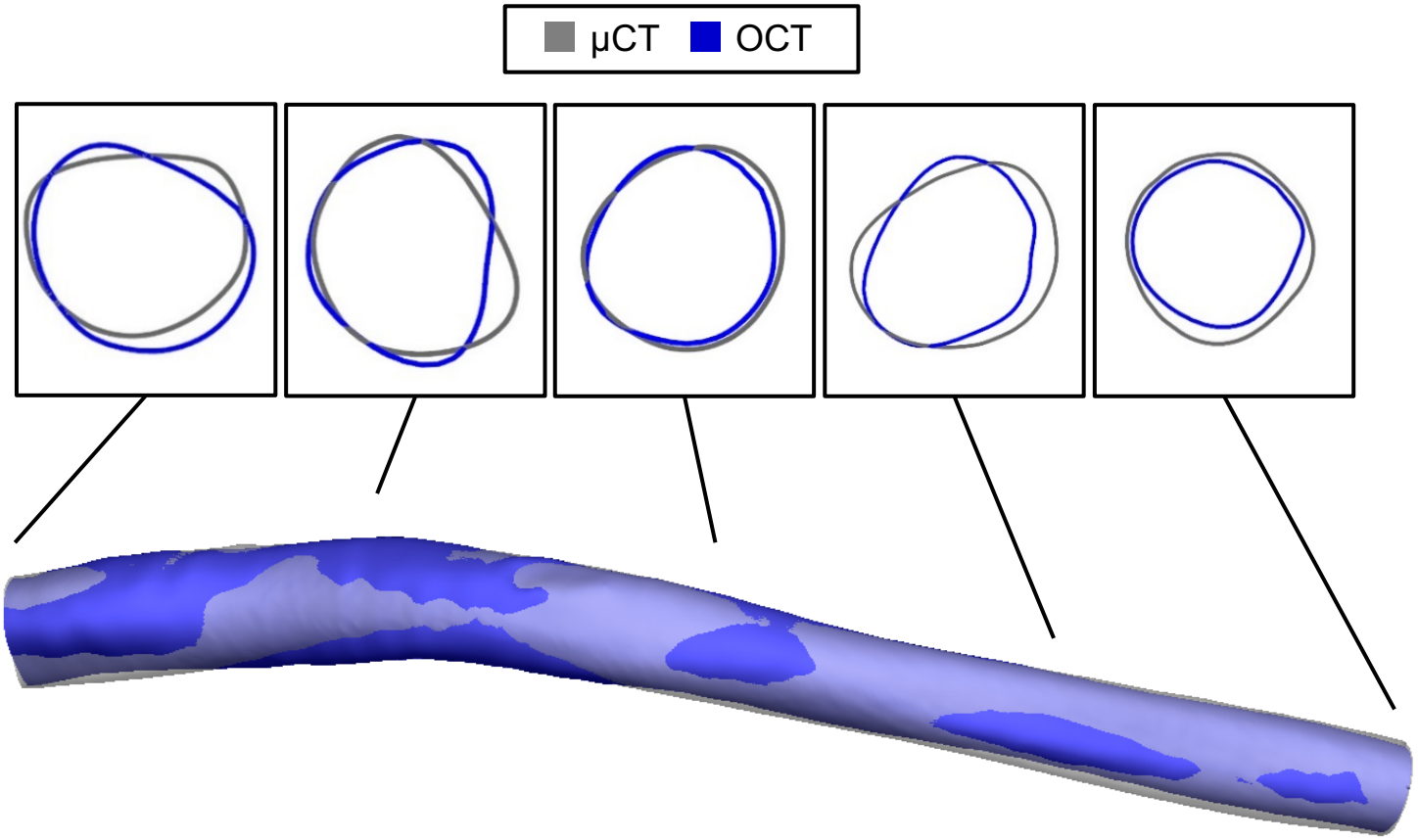




Migliori, Chiastra et al. *Med Eng Phys*, 2017

Validation: lumen reconstruction

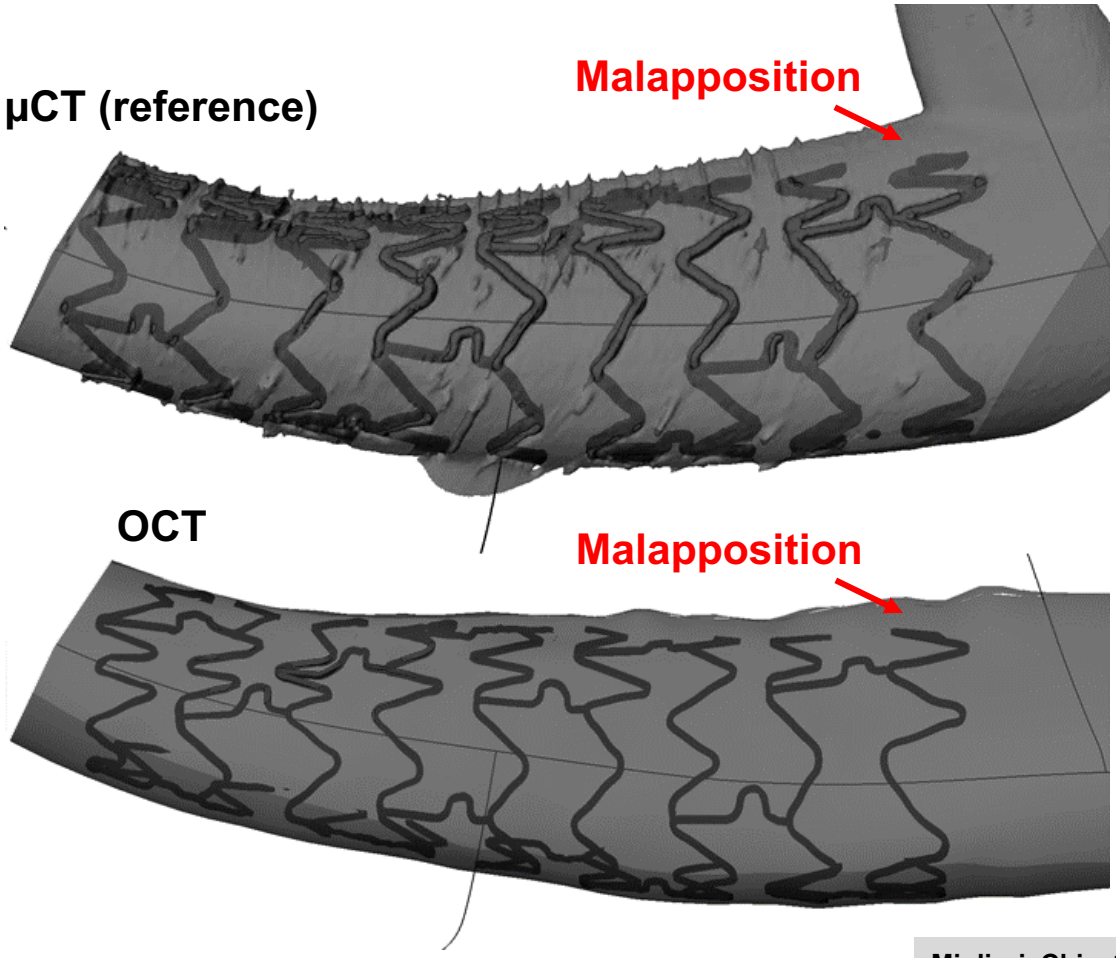
- Good replication of lumen cross-sections
- Twist error angle at the extremities
- Relative error for the lumen volume: 7.1%



Migliori, Chiastra et al. *Med Eng Phys*, 2017

Validation: stent reconstruction

- Good replication of stent design
- Regions of complete overlapping between stent reconstructions
- Distances between the two geometries (first 3 quartiles): 130 μm; 195 μm; 270 μm



Migliori, Chiastra et al. *Med Eng Phys*, 2017

Application to *in vivo* cases: an example

- **Right coronary artery**
- 3.5x28 mm **Xience Prime** (Abbott Vascular) + post-dilation

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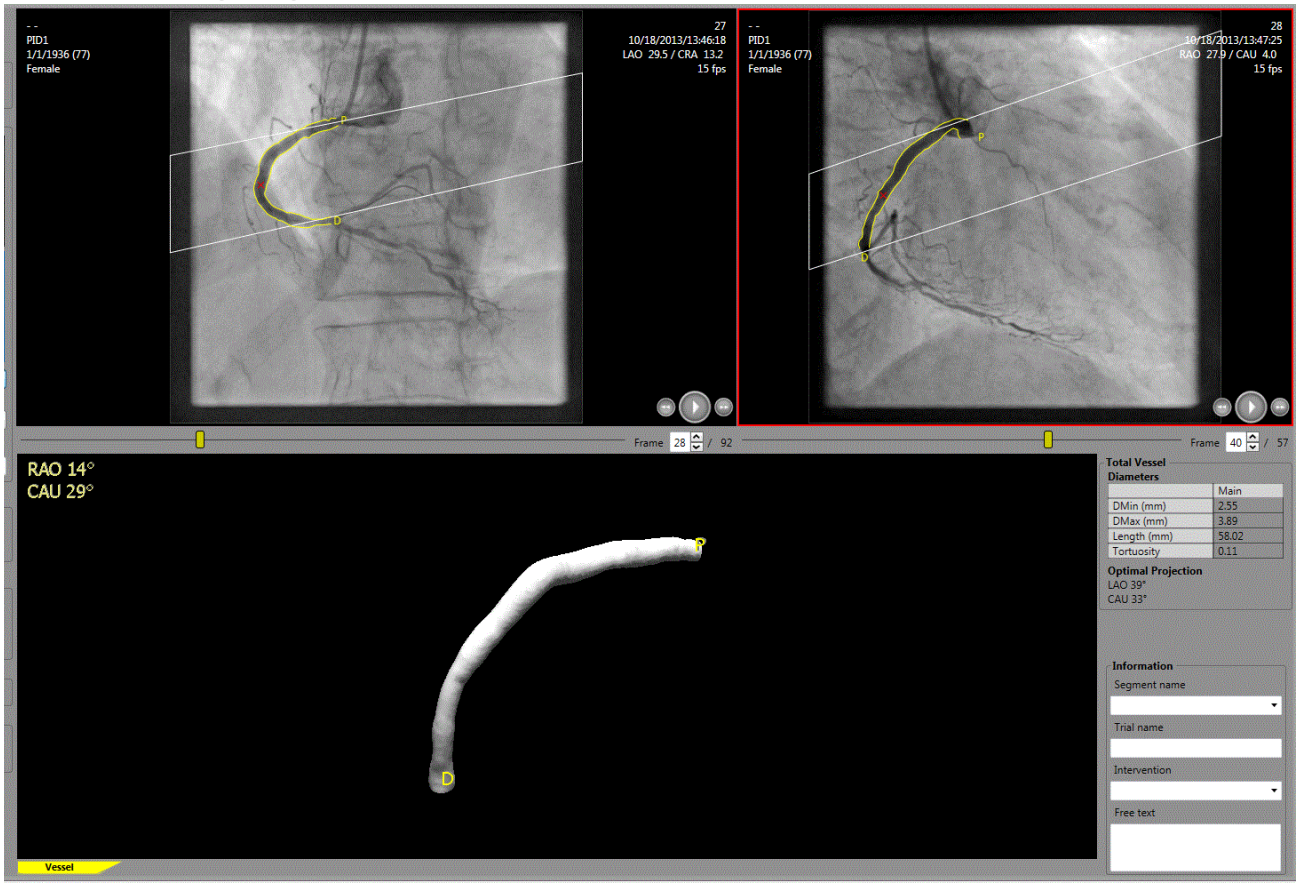
Fondazione Policlinico Universitario A. Gemelli
Università Cattolica del Sacro Cuore

Angiographic views for centerline extraction



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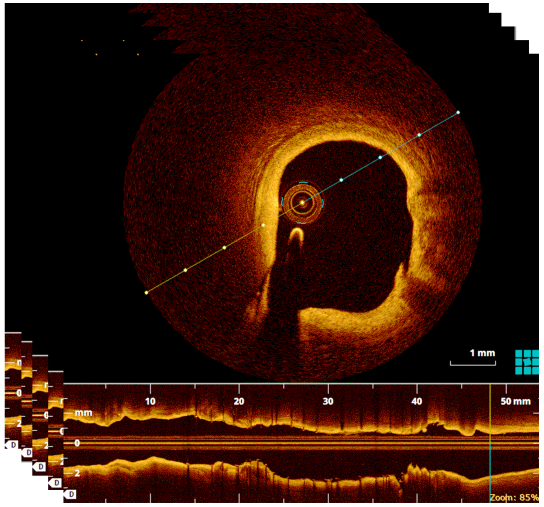

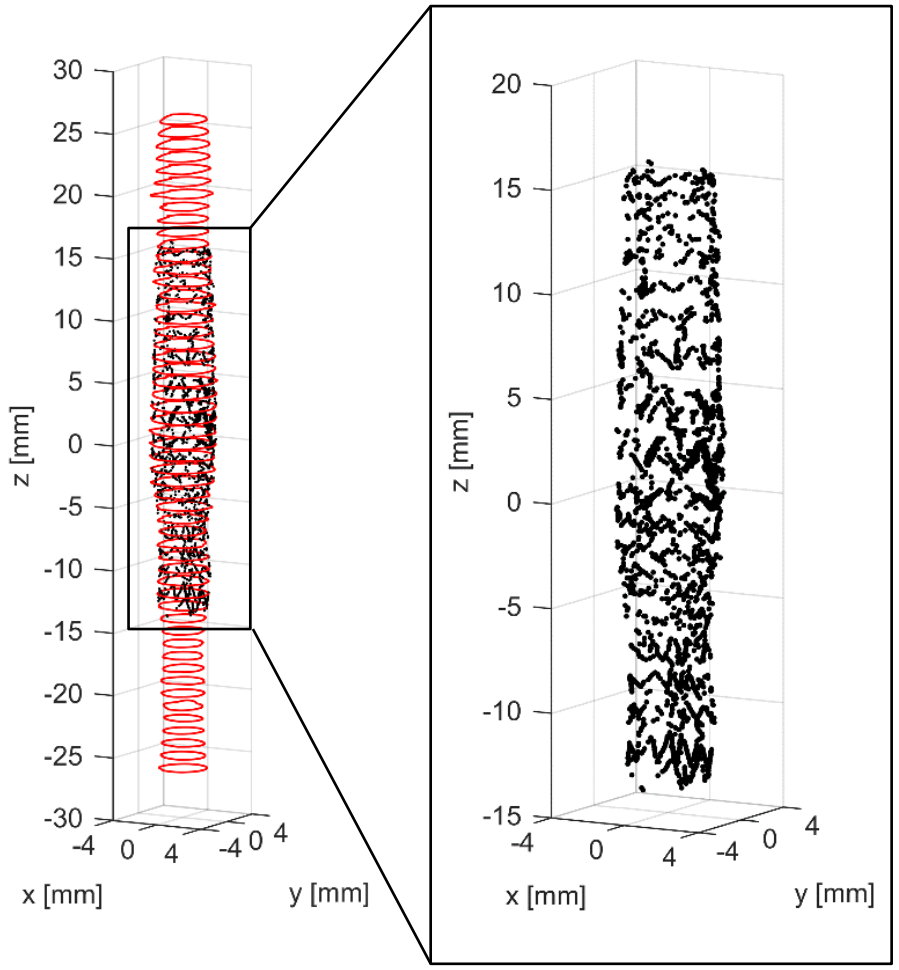

Chiastra et al. *PLoS ONE*, 2017

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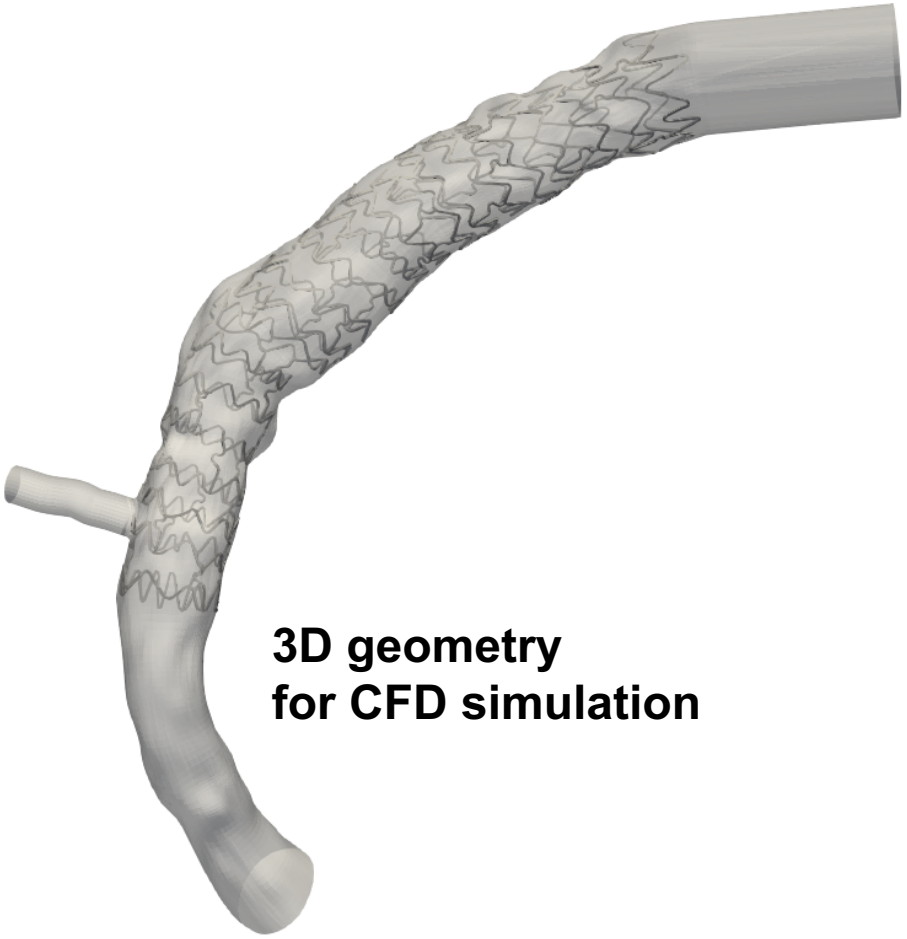
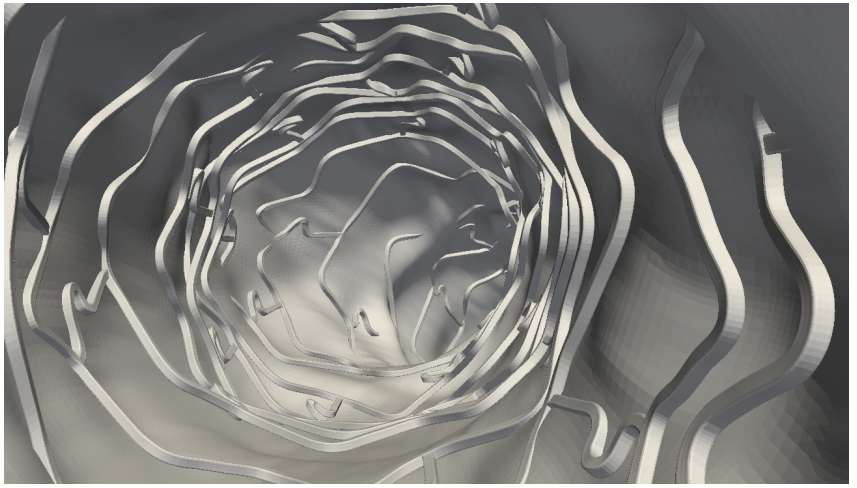
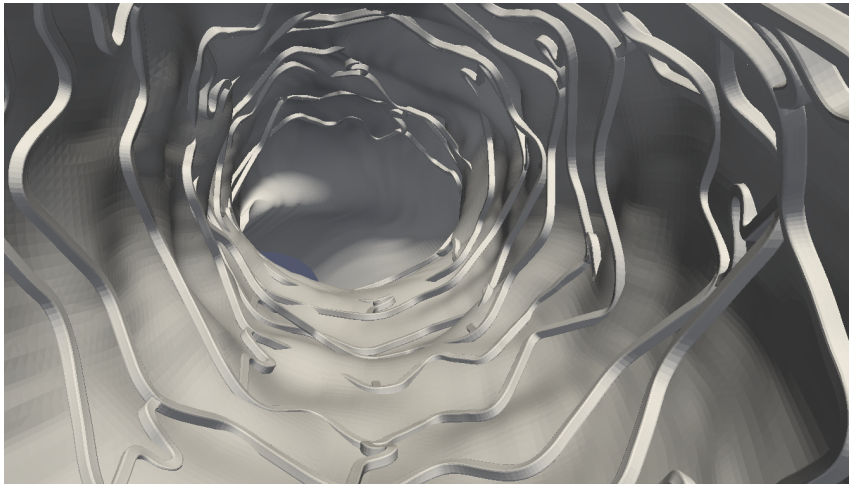


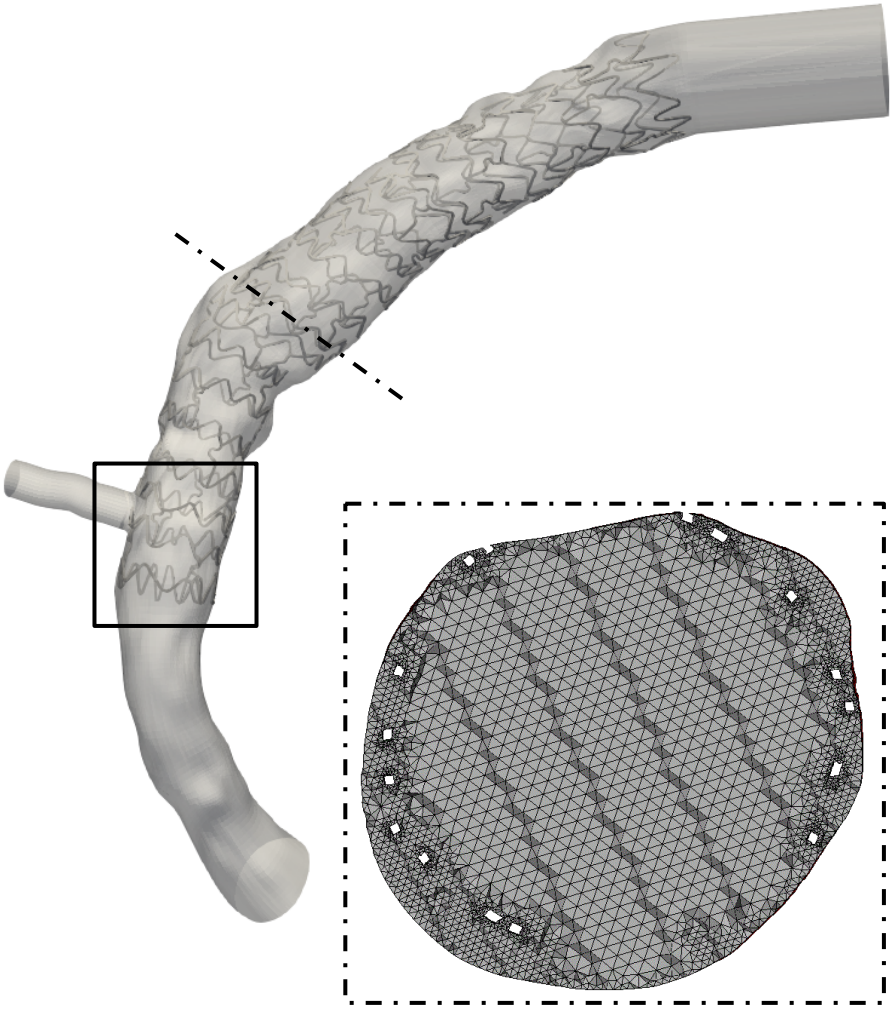
3D geometry
for CFD simulation





Application to *in vivo* cases: an example

■ **Mesh:** 5,957,992 tetrahedral elements

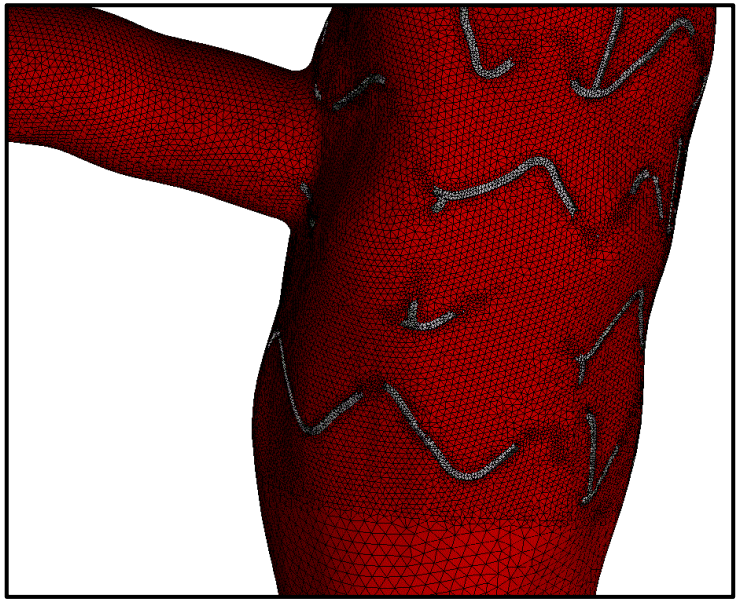


■ **Boundary conditions**

➢ **Inlet**: flow-rate based on frame count [1]

$$Q = \frac{15\frac{frame}{s}}{\#\,frames} \cdot V[ml] \cdot 60\frac{s}{min}$$

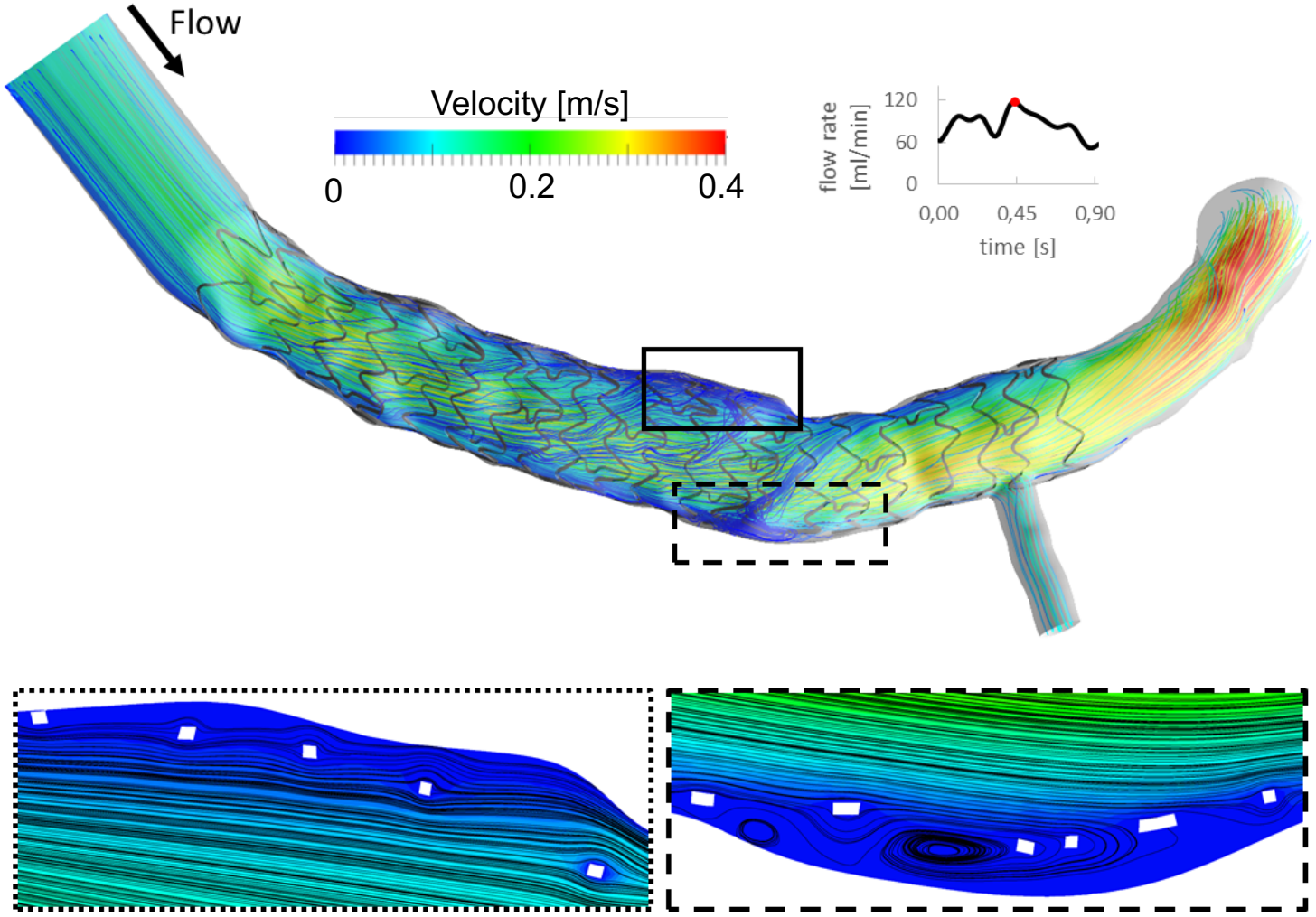
➢ **Outlet**: flow-split based on scaling law [2]
(MB = 94%, SB = 6%)



1. Sakamoto et al. *Am J Cardiol*, 2013
2. Van der Giessen et al. *J Biomech*, 2011

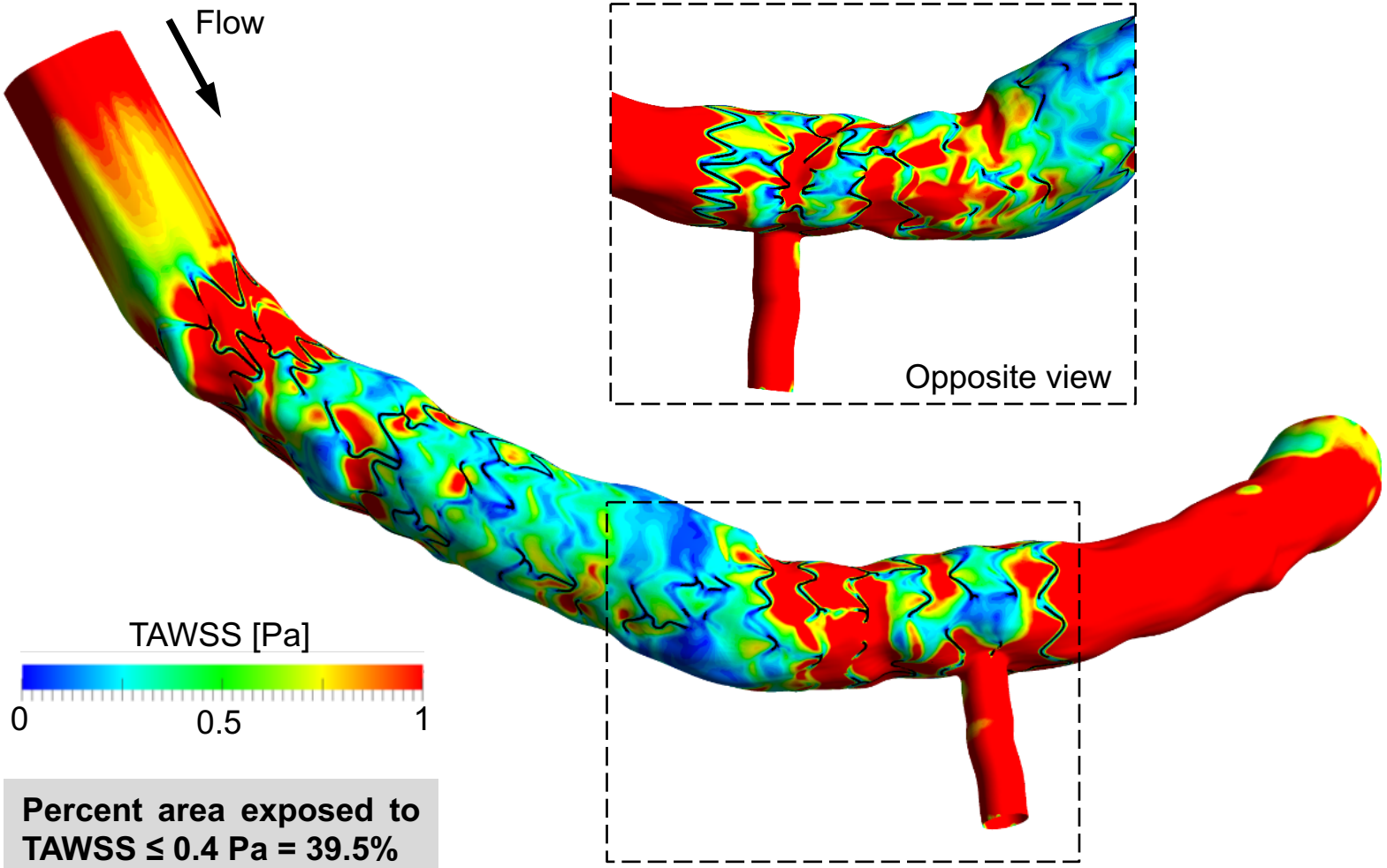
Application to *in vivo* cases: an example

- **Results: velocity**



Application to *in vivo* cases: an example

- **Results: time-averaged wall shear stress**



Percent area exposed to TAWSS ≤ 0.4 Pa = 39.5%

Conclusions

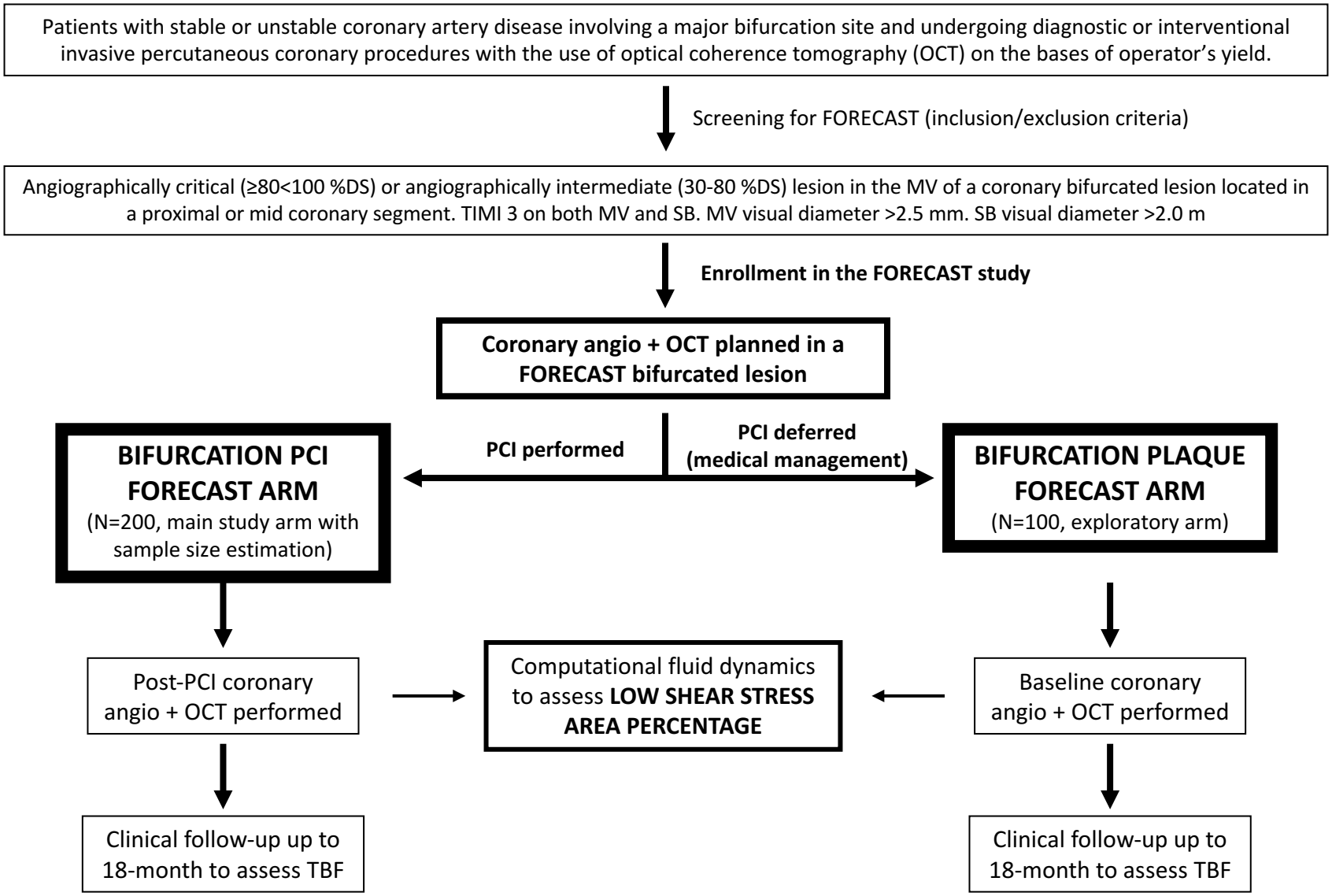
- **3D reconstruction method** of **stented coronary bifurcation models** from **OCT** for **fluid dynamics simulations**
  - Able to reconstruct continuous 3D stent geometries with high accuracy
  - Able to capture malapposed struts
  - Able to reconstruct every type of coronary stent (i.e. with rectangular / circular cross-section)

- **Validation** of the reconstruction method
  - Good replication of the lumen and stent
  - The more the landmarks, the less the twist angle error between OCT frames

- Application of the reconstruction method **patient-specifc cases**

⇨ **EBC FORECAST**

EBC FORECAST flow-chart



Research team

- Gabriele Dubini 
- Susanna Migliori 
- Marco Bologna 

- Luca Mainardi 
- Eros Montin 
- Lorenzo Genuardi 

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- Francesco Migliavacca
- Claudio Chiastra
- Cristina Aurigemma
- Francesco Burzotta

H2020 Marie Skłodowska-461 Curie European Training Network
H2020-MSCA-ITN-2014 VPH-CaSE, www.vph-case.eu

VPHCaSE
Cardiovascular Simulation and Experimentation for Personalised Medical Devices

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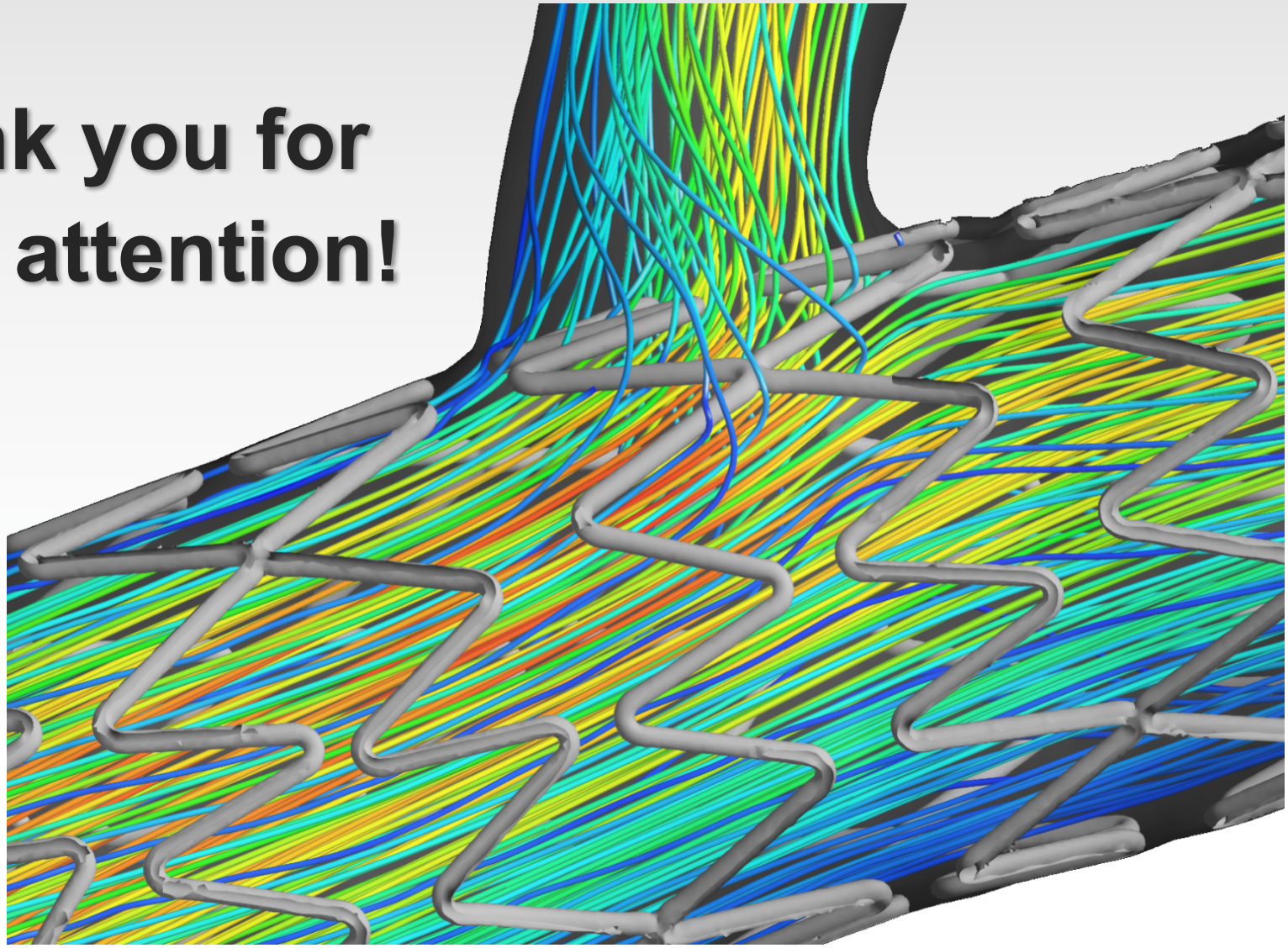
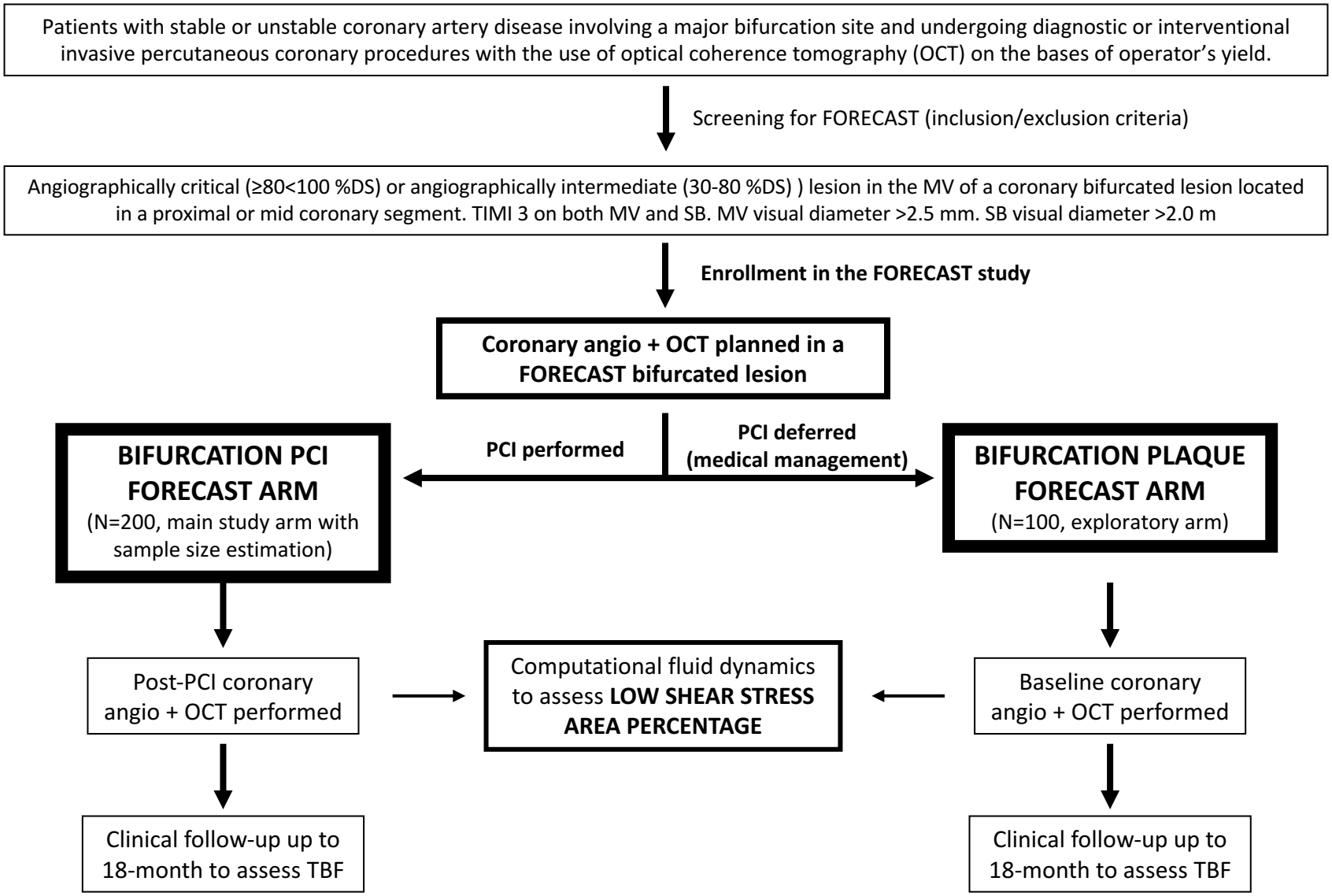
Thank you for your attention!



EBC FORECAST flow-chart



Application to *in vivo* cases: Patient 2

- Distal **right coronary artery**
- 3.5x24 mm **Nobori** (Terumo) + post-dilation

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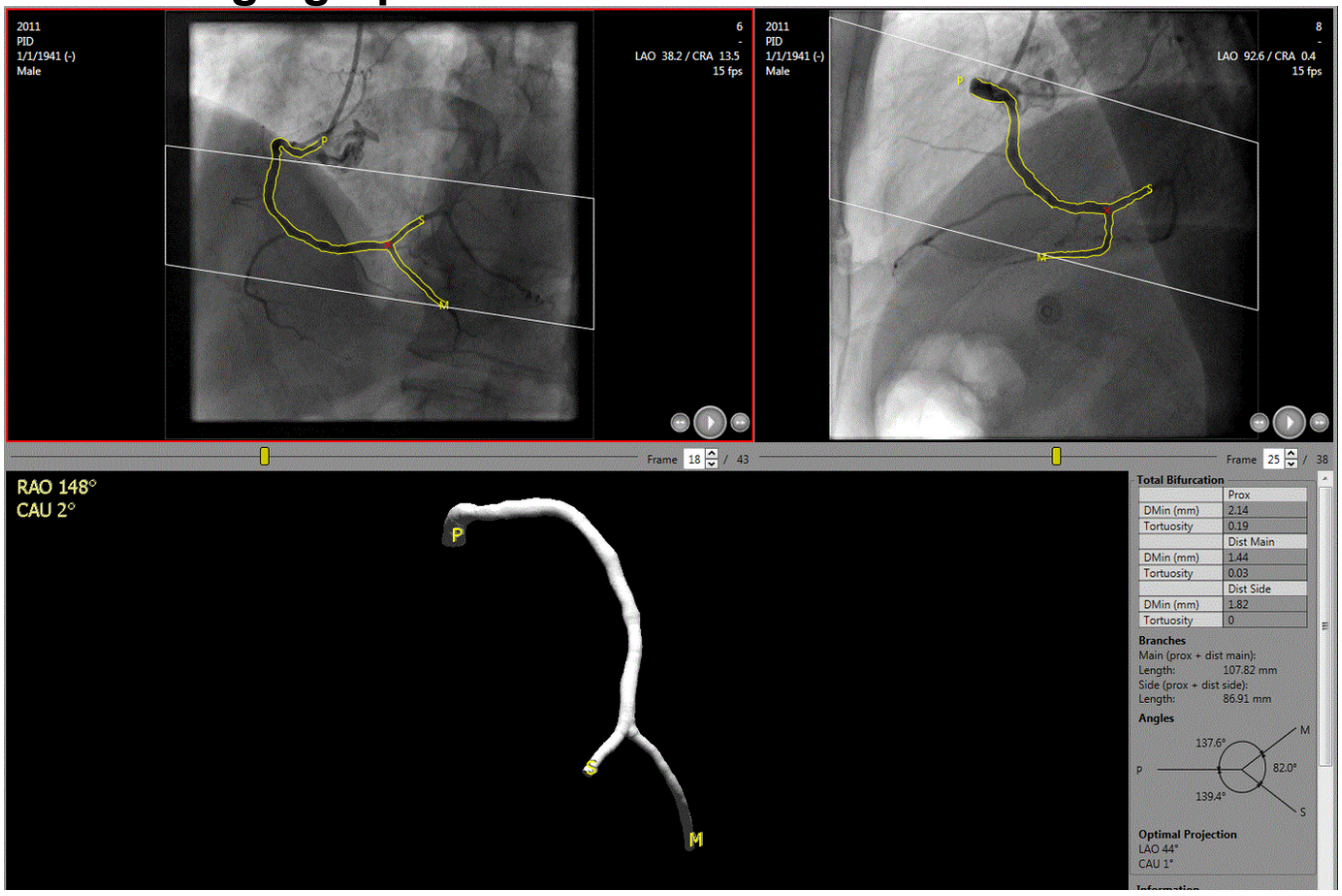
Angiographic views for centerline extraction



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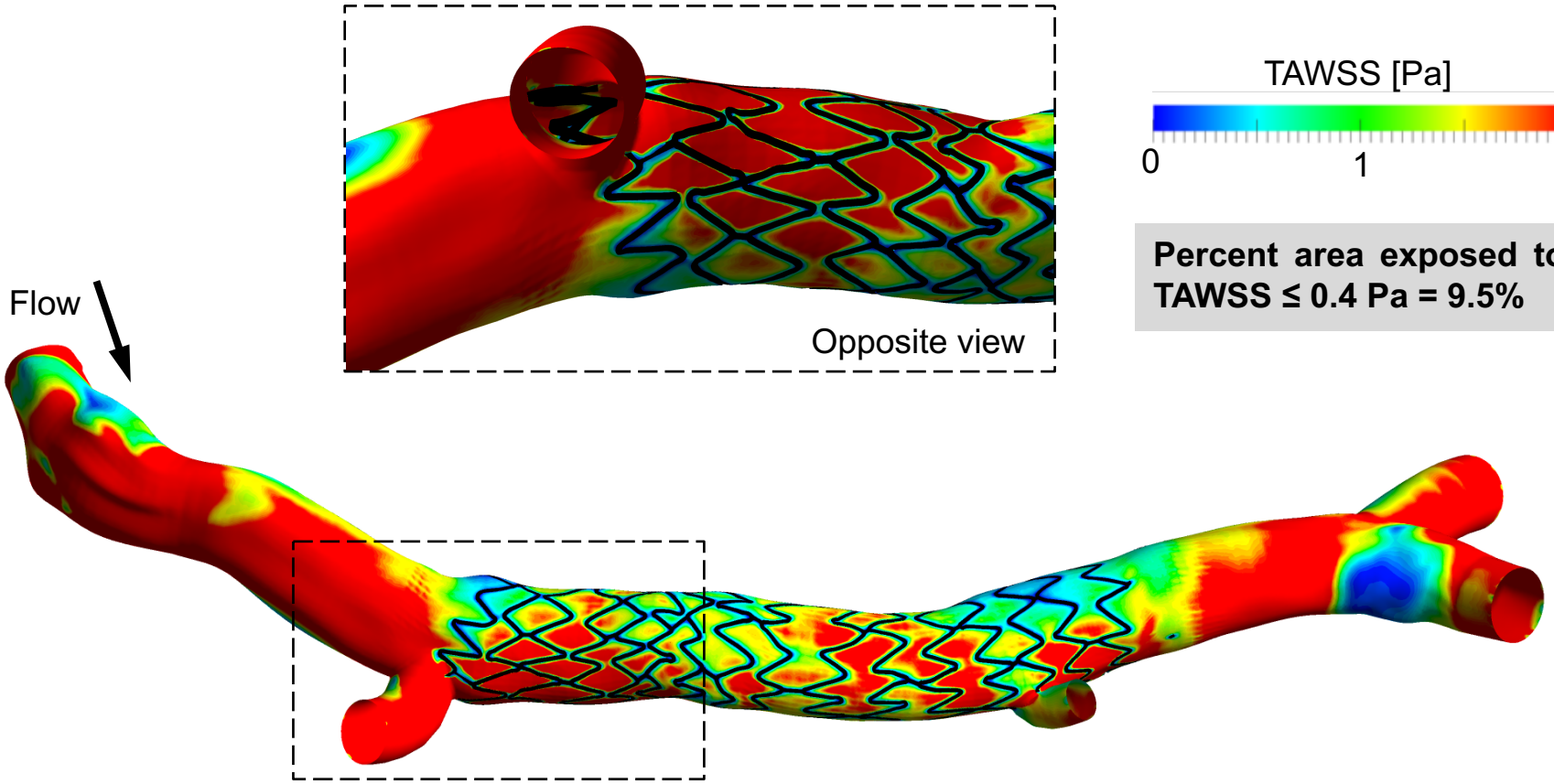

Percent area exposed to TAWSS ≤ 0.4 Pa = 9.5%