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Institut Thématique Multi-Organismes
Technologies pour la santé

Towards a patient-specific simulation of percutaneous transluminal angioplasty

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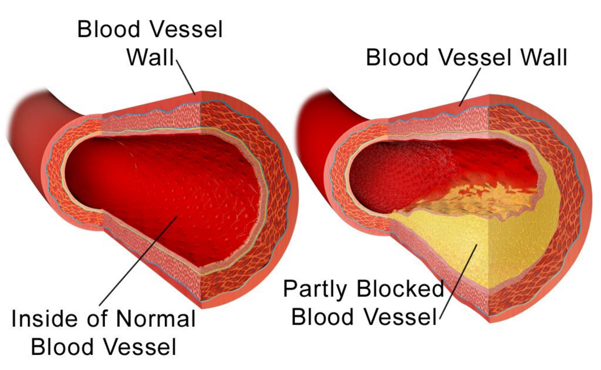
Context & Objectives

Atherosclerotic Plaque

- **Accumulation** of *lipids, calcium and fibrin at the inner wall of the arteries*

➔ **Reducing** blood flow mobility
➔ **Effecting** irrigated organs



Healthy vessel **Stenosed vessel**

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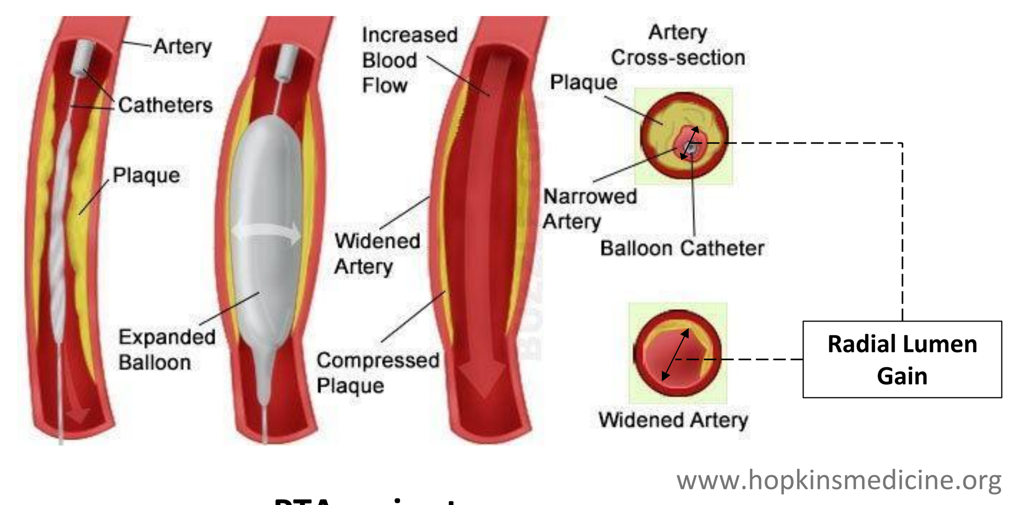
Localization

- Carotid arteries ➔ *20%* of **ischemic strokes**
- Peripheral arteries ➔ **claudication**

Percutaneous transluminal angioplasty (PTA)



PTA main steps

❑ **Advantages** (*benefits*):

- Endovascular *treatment*
- *Mini-invasive* procedure
- *Fewer risks*

❑ **Disadvantages** (*risks*):

- *Restenosis*
- *Dissection (wall tear)*
- *Perforation (hole development)*

Challenging for the surgeons: **choosing the adequate balloon, maximizing lumen gain**, *without damaging the arterial tissue*

State of the Art

- Several FEM studies modelled **PTA** in *2D geometries*, others in *3D idealized geometries* and few others in *Patient-specific geometries*

(Sadat et al., 2010; Karimi et al., 2013; Auricchio et al. 2011)

- However, *Endov. Treat. Prediction* using **FEM** still **limited by**:

➢ Patient-specific stenosed arterial *geometry & composition*
(Several imaging techniques available with each it's own limitations)
➔ **CT** most commonly used in PTA protocols

➢ *Plaque material composition and mechanical behavior model*

Main objective

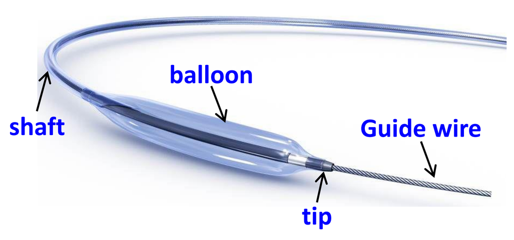
- Modelling **Permanent deformations** following **PTA** in stenosed arteries using **FEM**:

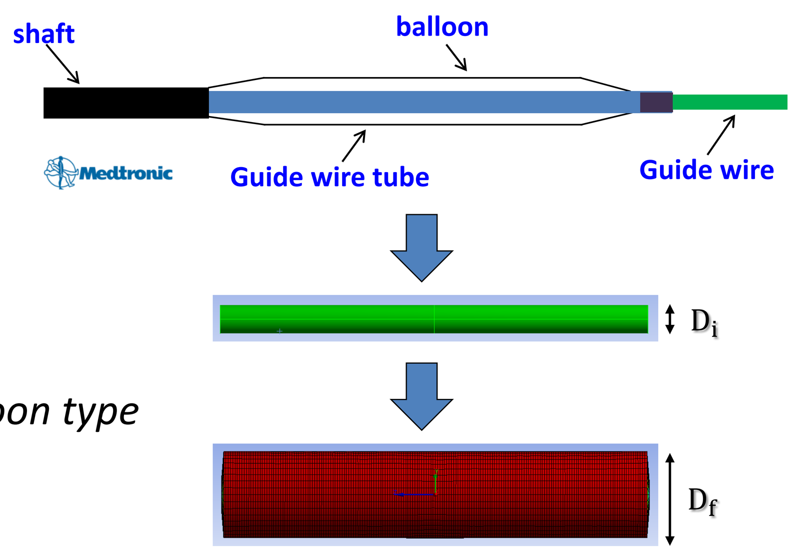
➢ Non-compliant balloon simulated in idealized stenosed artery

➢ Patient-specific plaques (geom. & comp.) extracted from CT images using segmentation approach

Balloon Catheter Model

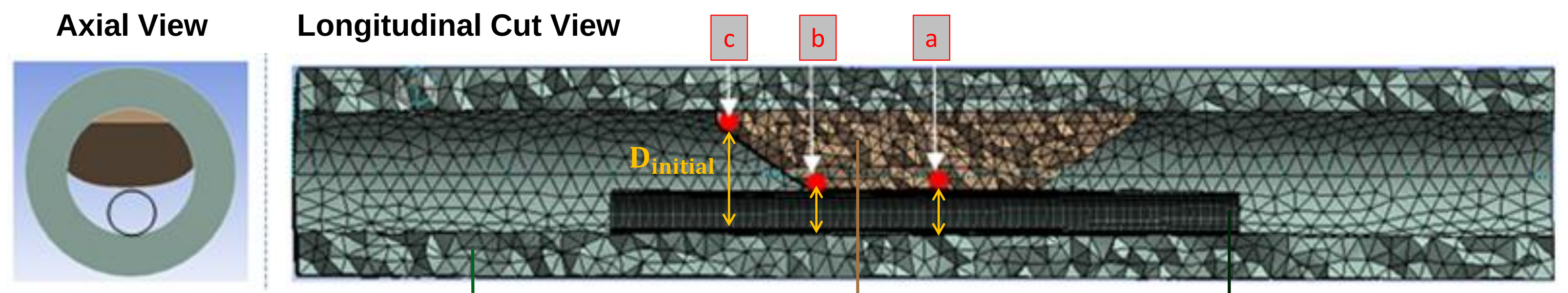
Balloon Geometry in reality:





- Displacement-driven balloon
  ➔ mimicking the **Non-compliant** (*very stiff*) balloon type
- Inflation Ratio: $\frac{D_f}{D_i} = 3$

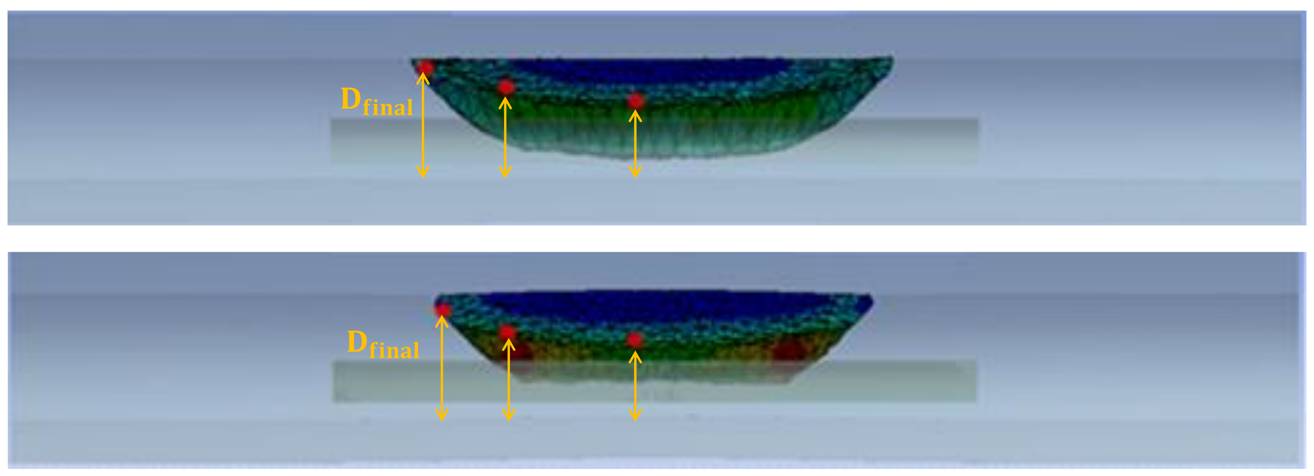
FE simulation of PTA in an idealized stenosed artery



Geometry & Mesh: Artery — *Tetrahedral solid elements*; Plaque — **60 %** stenosis, *Tetrahedral solid*, **Calcified** vs. **Lipid**; Balloon — *Quadrilateral shell elements*

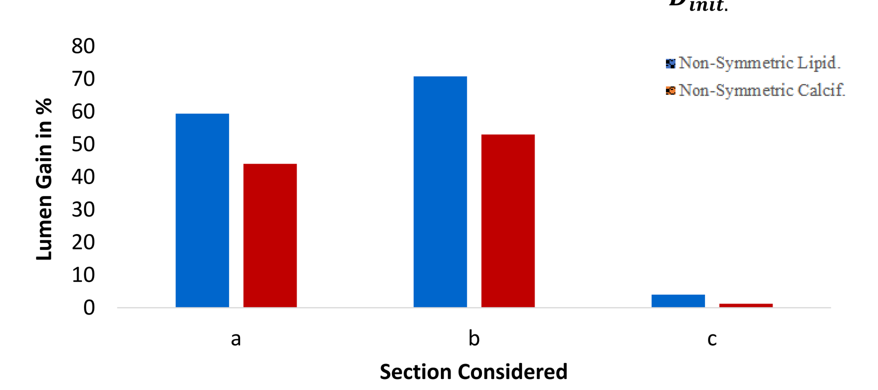
Material Model: **Neo-Hookean** (Artery), **Bilinear Plastic** (Plaque)

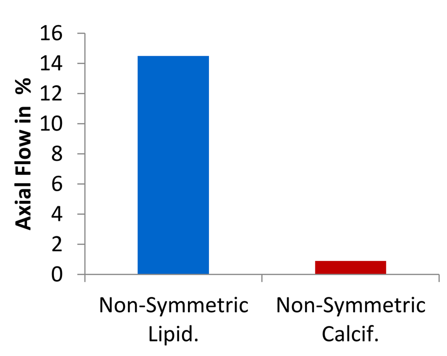
Plastic strain after Balloon deflation

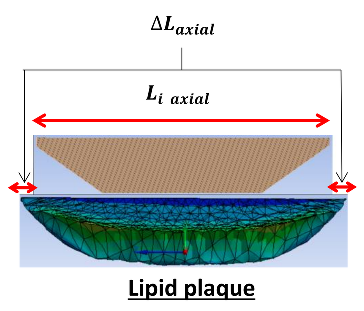


Lumen Gain in % *after balloon deflation*: $LG = \left(\frac{D_{final}}{D_{init.}} - 1\right) \times 100$

Plaque Axial Flow in % *after balloon deflation*: $AF = \frac{\Delta L_{axial}}{L_{i\ axial}} \times 100$



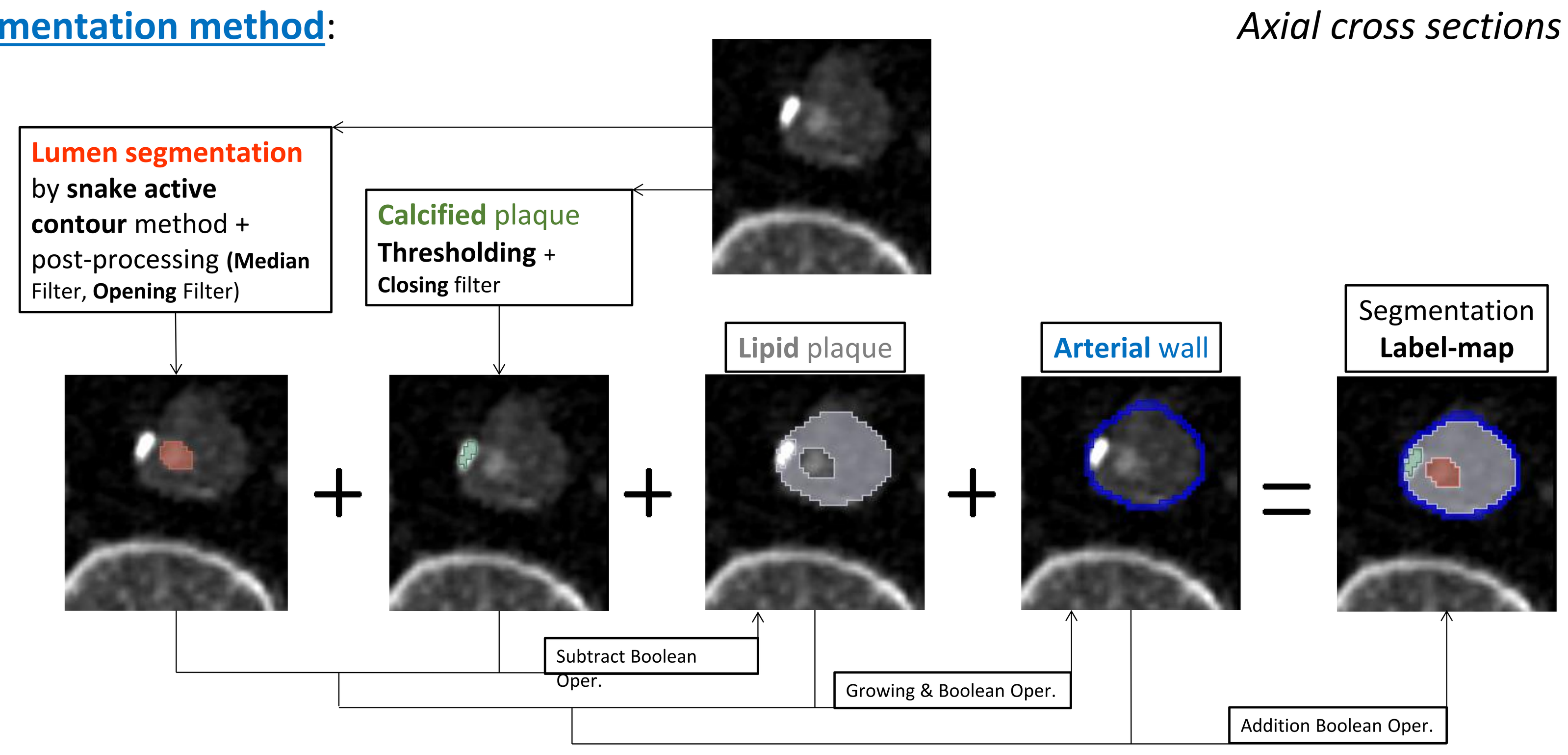




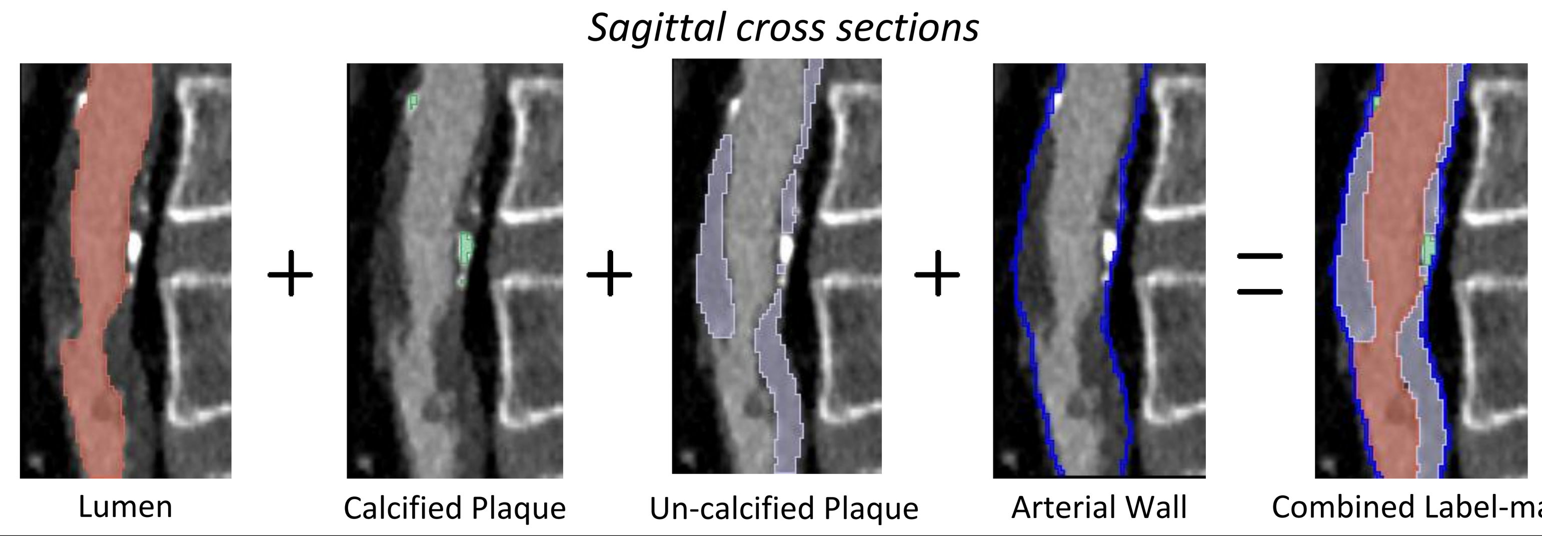
- **Higher lumen gain** (*LG*) along **lipid plaque** (*at* ***a***, ***b*** *and* ***c***: blue vs. orange): *softer plaque*
- **LGs** are of **high values** at sections **a** and **b** while **low** at **c** ➔ *Plaque thickness highly influences LGs*
- **Higher axial flow** in **lipid plaque**: *lower deformation resistance* ➔ **Importance of PTA 3D modeling**

Patient-specific plaque geometry segmentation

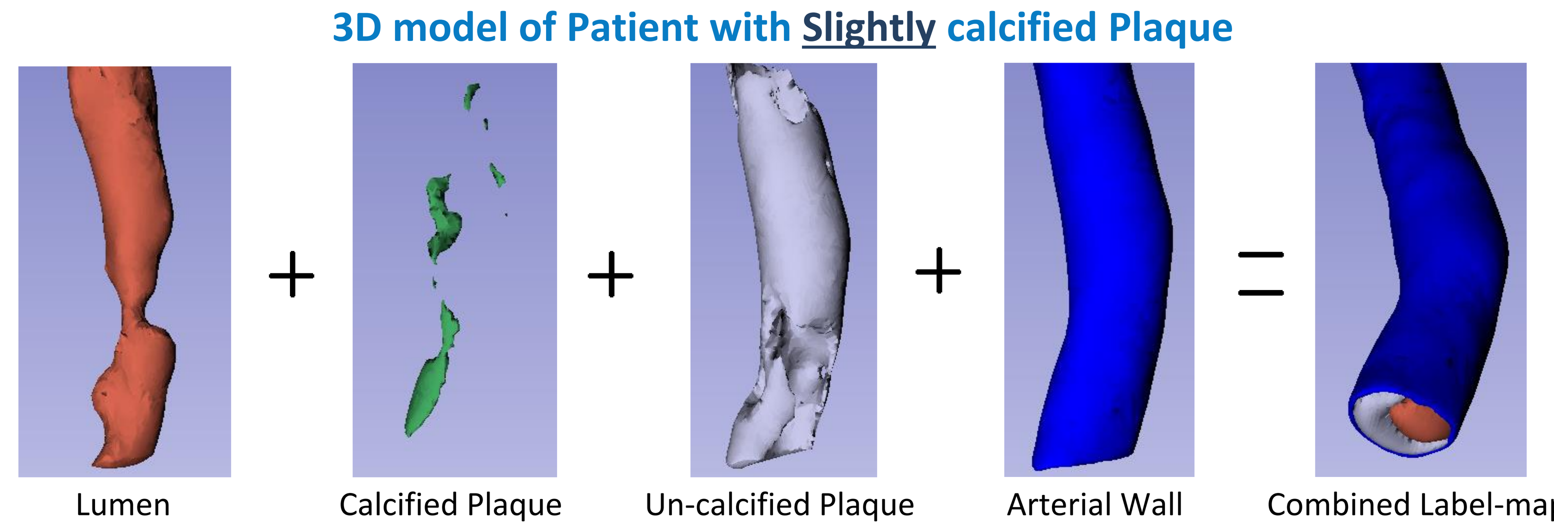
Segmentation method: *Axial cross sections*



Sagittal cross sections

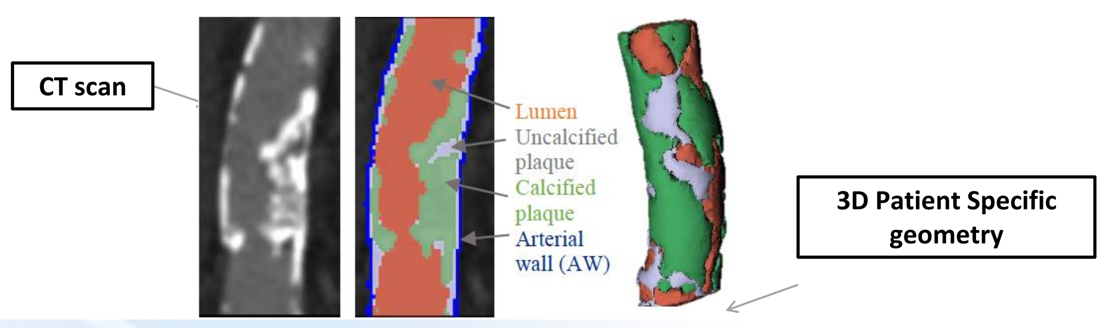


3D model of Patient with Slightly calcified Plaque



Conclusion and Perspectives

- **Patient-Specific Balloon Angioplasty** *simulations* **in stenosed arteries**
  - **Pre- and Post- operative medical images** would be **required**



➔ A step towards predictive simulation for the *planning of endovascular treatment of stenosis*

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