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Influence of plaque geometry and composition on numerically simulated balloon angioplasty outcomes

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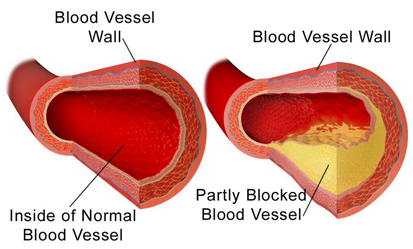
Context & Objectives

Atherosclerotic Plaque

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

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



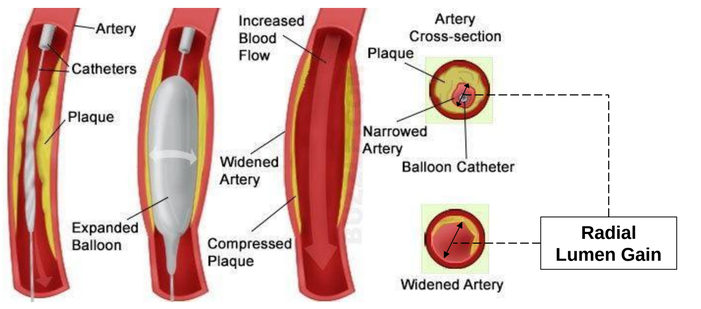
Healthy vessel **Stenosed vessel**

www.study.com

Localization

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

Percutaneous transluminal angioplasty (PTA)



www.hopkinsmedicine.org

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)

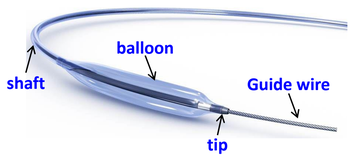
- However, *Endovascular Treatment prediction* using **FEM** still **limited by**:
  - Atherosclerotic *plaque material composition and mechanical behaviors modeling*
  - *Residual deformations modeling after PTA*

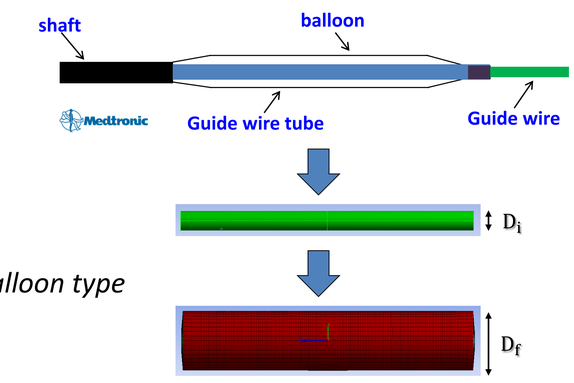
Main objective

- Modeling **Permanent deformations** following **PTA** using **FEM**:
  - Non-compliant balloon simulated in idealized stenosed artery with symmetric vs. non-symmetric plaque geometries

Balloon Catheter Model

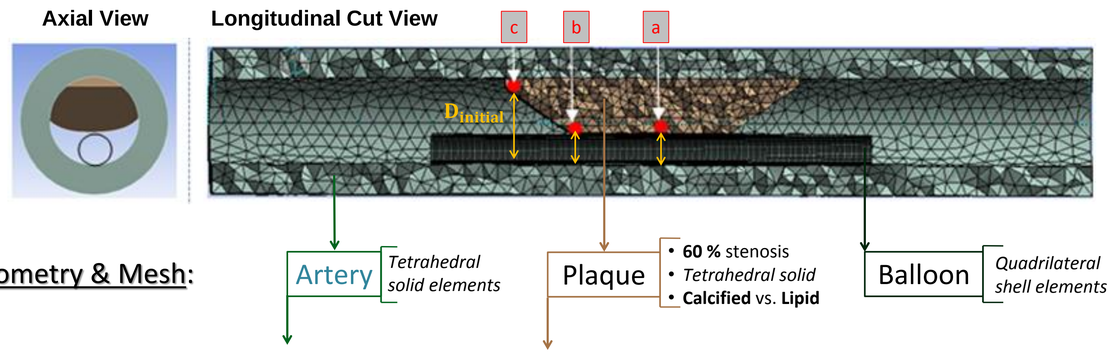
Balloon Geometry in reality:





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

Non-symmetric plaque geometry: Lipid vs. Calcified



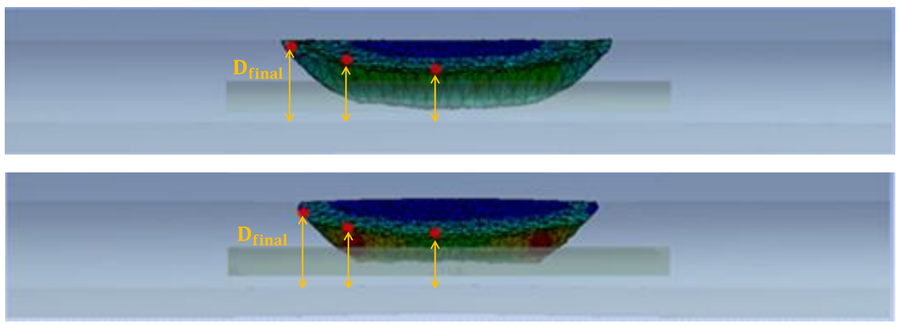
Geometry & Mesh:

Material Model: **Neo-Hookean** **Bilinear Plastic**

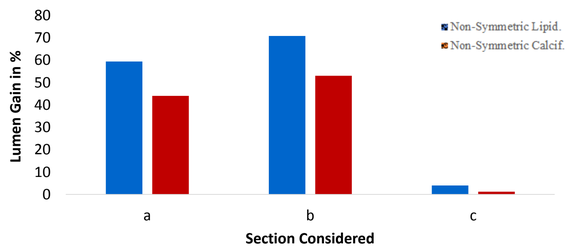
Plastic strain after Balloon deflation

Lipid Plaque

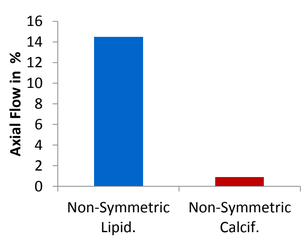
Calcified Plaque

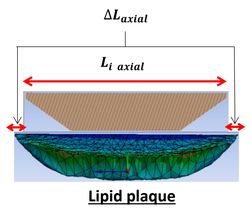


Lumen Gain in % *after balloon deflation*: $LG = (\frac{D_{final}}{D_{init.}} - 1) \times 100$



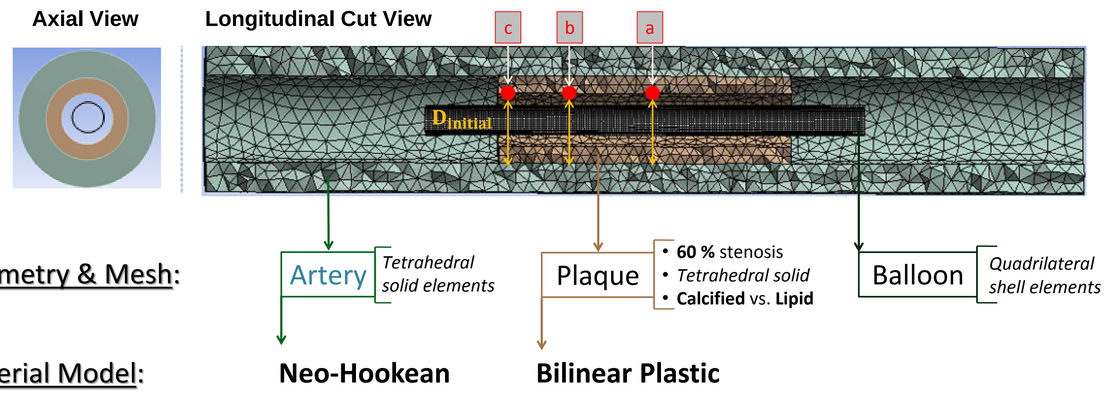
Plaque Axial Flow in % *after balloon deflation*: $AF = \frac{\Delta L_{axial}}{L_{i\ axial}} \times 100$





- **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**

Symmetric plaque geometry: Lipid vs. Calcified



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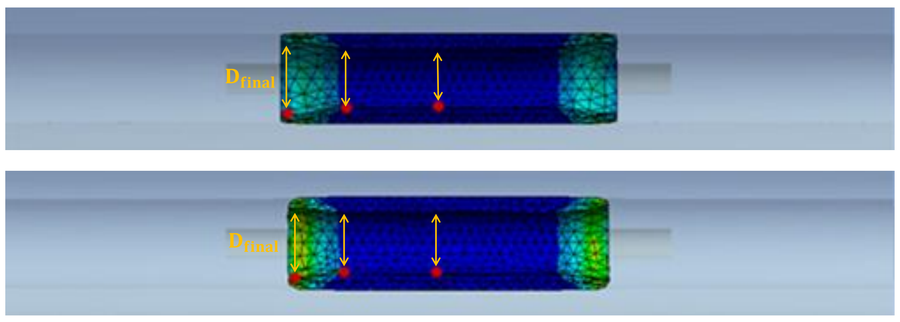
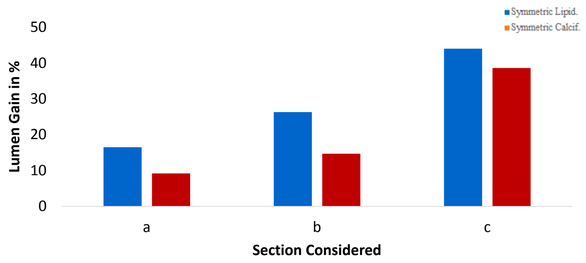
Lipid Plaque

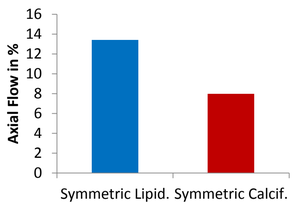
Calcified Plaque

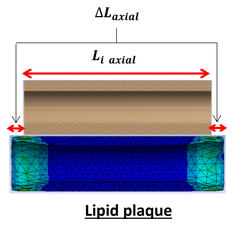


Lumen Gain in % *after balloon deflation*:



Plaque Axial Flow in % *after balloon deflation*:



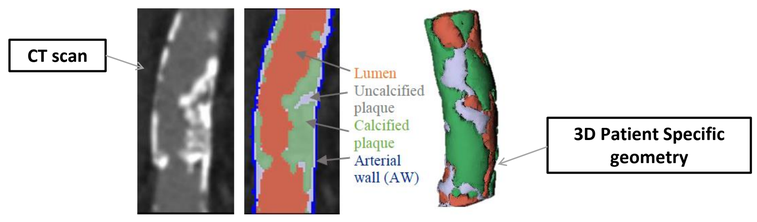


- **Lumen gain** (**LG**) increases towards plaque edges (*LGc > LGb > LG>a*)
- **Higher lumen gain** and **axial flow** along **lipid plaque** (blue vs. orange): *softer plaque*
  ➔ Importance of **modeling PTA** in **3D**

Conclusion

- **Lipid** plaques experiences higher **lumen gains** and **axial flows** (*composition influences*)
- **Thicker** plaques experiences higher **LGs** (*geometric influences*)
- Both **radial LGs** and **axial flows** exists ➔ **PTA** should be **modelled in 3D**

- **Perspectives**: **Patient-Specific Balloon Angioplasty** *simulations* **in stenosed arteries**



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