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Bending of a Stented Atherosclerotic Artery

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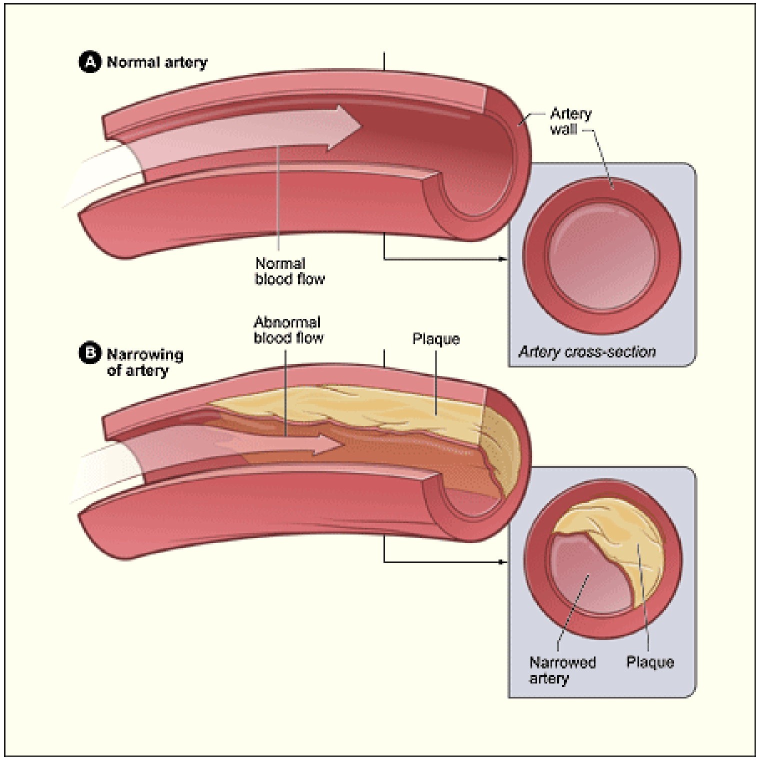
Atherosclerosis

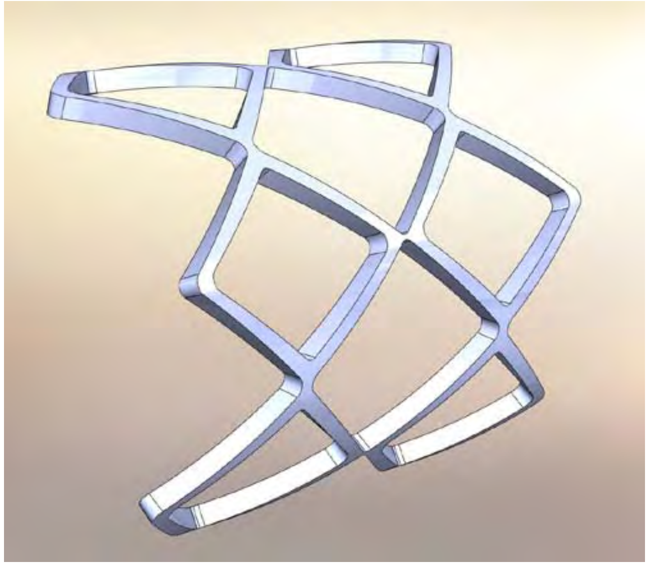
- Characterized by deposition of plaque on inner walls of arteries
- Intimal layer thickens
- Lipid and fibrous tissue get deposited [1]
- Current stents not ideal for use in arteries that undergo large bending

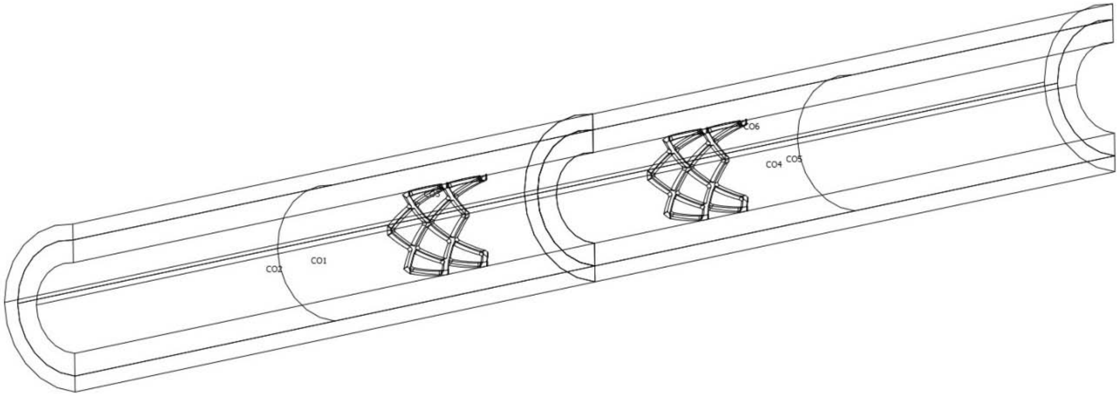


[2]

Segmented stent design

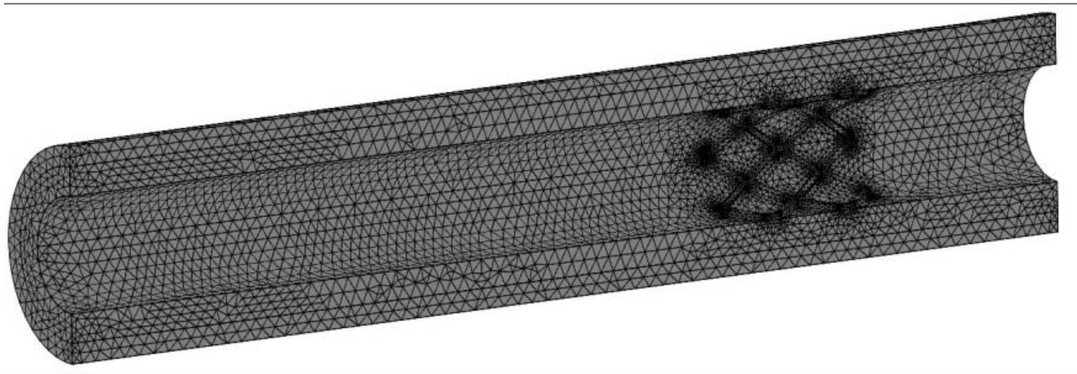
- 6 mm longitudinal length
- 1.8 mm inner radius
- 0.2 mm thickness

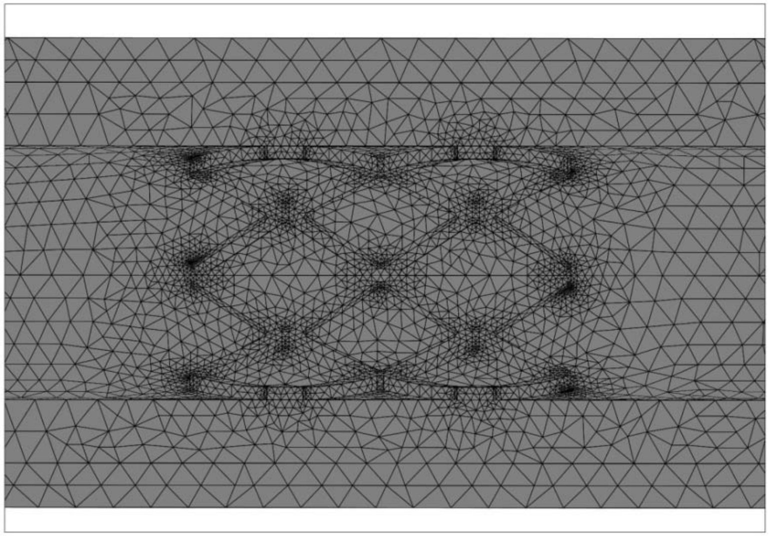




Mesh with segmented stent

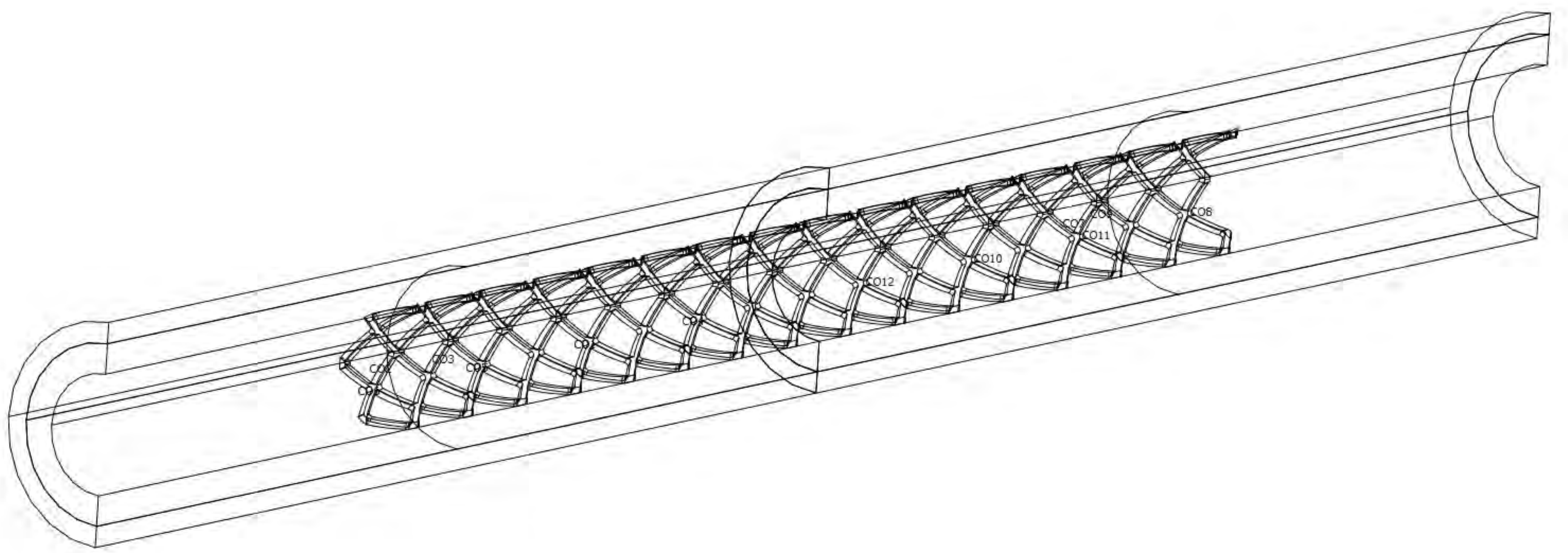
- 0.6 mm in artery
- 0.5 mm in plaque
- 0.24 mm in stent and plaque-stent interface
- DOF > 560,000





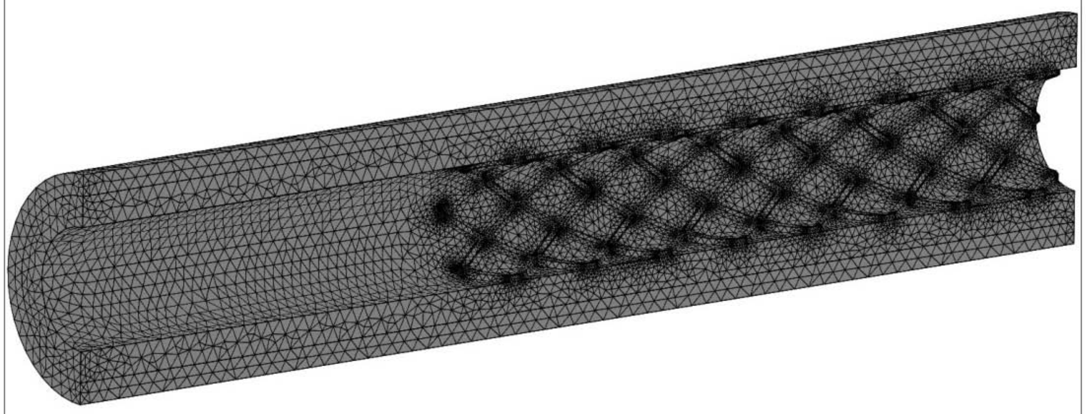
Full-length stent

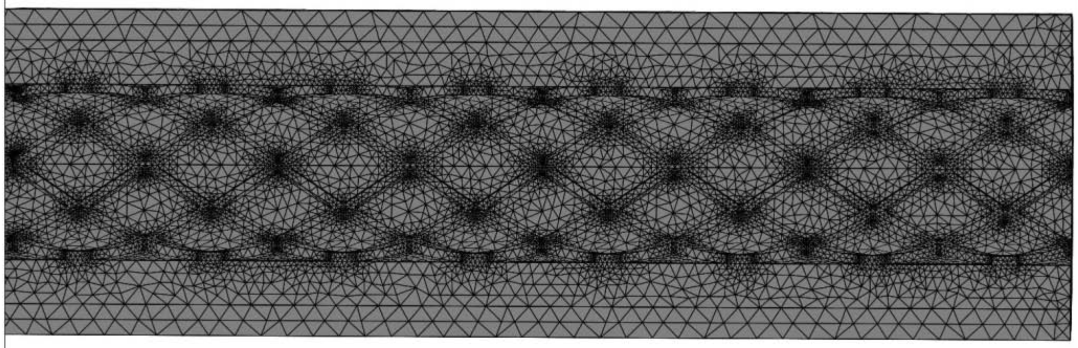
- 48 mm longitudinal length
- 1.8 mm inner radius
- 0.2 mm thickness



Mesh with full-length stent

- 0.6 mm in artery
- 0.5 mm in plaque
- 0.24 mm in stent and plaque-stent interface
- DOF > 900,000





Artery and plaque

- Artery
  - 3 mm inner radius
  - 0.7 mm thickness
  - 8 cm length
- Plaque
  - 2 mm inner radius
  - 1 mm thickness
  - 8 cm length
- Neo-Hookean model with K = 20μ
  - Artery: μ = 6 MPa [3]
  - Plaque: μ = 6 kPa but can vary from 0.1 to 60 kPa [4, 5]

$$W = \frac{\mu}{2}(\bar{I}_1 - 3) + \frac{K}{2}(J-1)^2,$$

$$\bar{I}_1 = \frac{B_{kk}}{J^{2/3}}$$

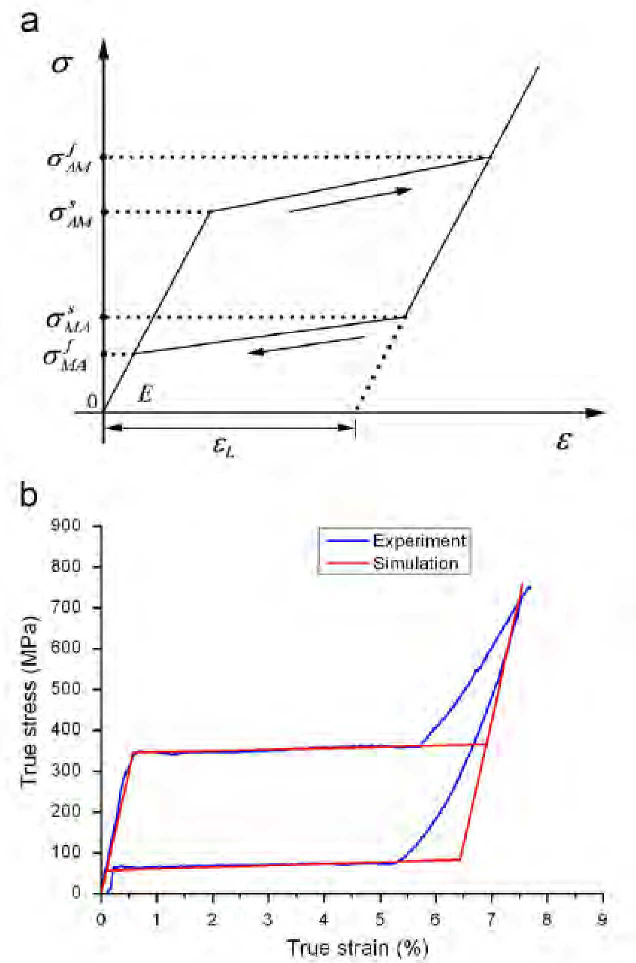
$$B_{ij} = F_{ik}F_{jk},$$

$$J = \det \mathbf{F},$$

$$F_{ij} = \delta_{ij} + \frac{\partial u_i}{\partial X_j},$$

Nitinol stent model

- Stent: linearly elastic model
  - E = 60 GPa
  - ν= 0.33
- Variable Young's modulus
- Hysteresis loop: loading and unloading curves are different
- Linearly elastic behavior for loading up to 346 MPa [6]

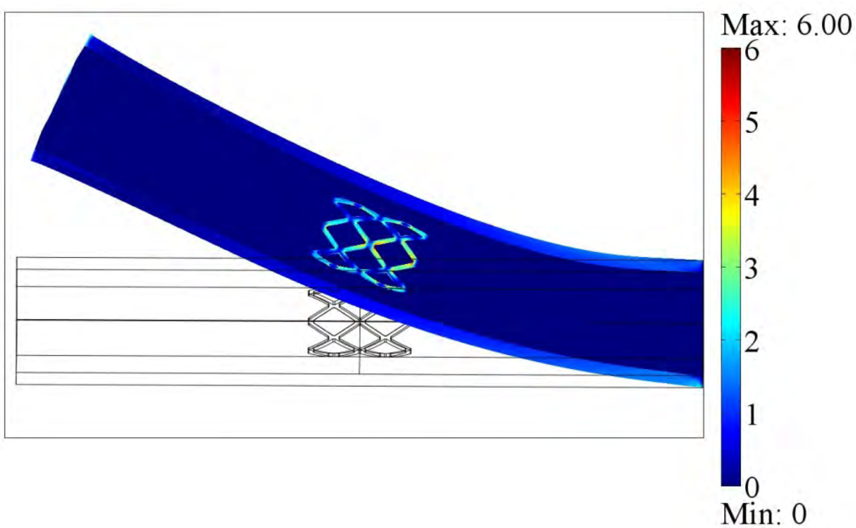


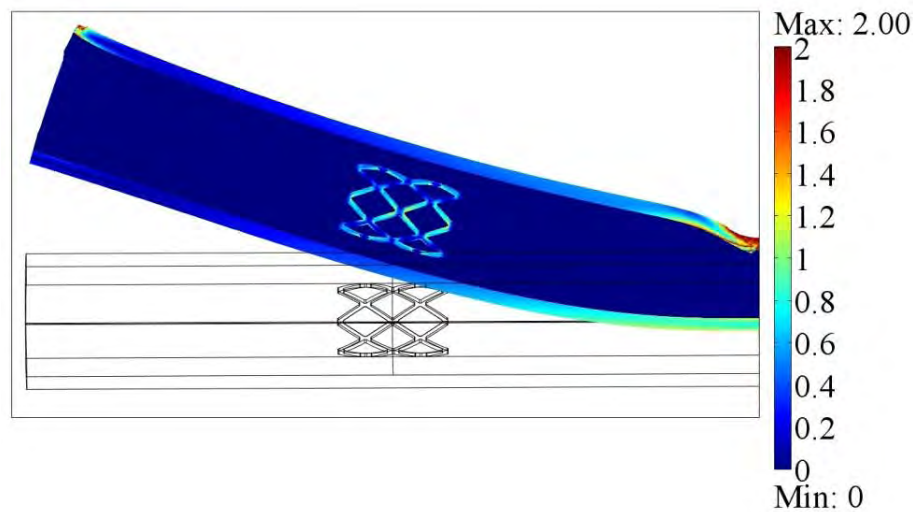
Boundary conditions

- First set (BC-I)
  - Fixed median planes of artery and plaque
  - Applied displacement (in 1 mm steps) on surface of artery end
- Second set (BC-II)
  - Used symmetry on median planes of artery and plaque with a fixed single point
  - Applied displacement (in 1 mm steps) on single point on artery end

Von Mises stress

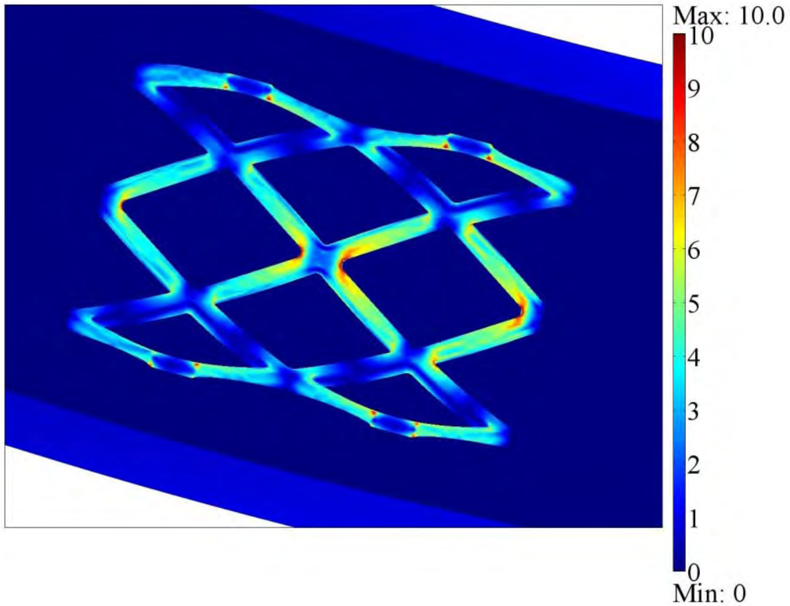
BC-I	BC-II
• 4 cm spacing • 13 mm applied displacement • Max stress: 8.48 MPa • Average stress: 1.19 MPa	• 4 cm spacing • 13 mm applied displacement • Max stress: 2.15 MPa • Average stress: 0.33 MPa



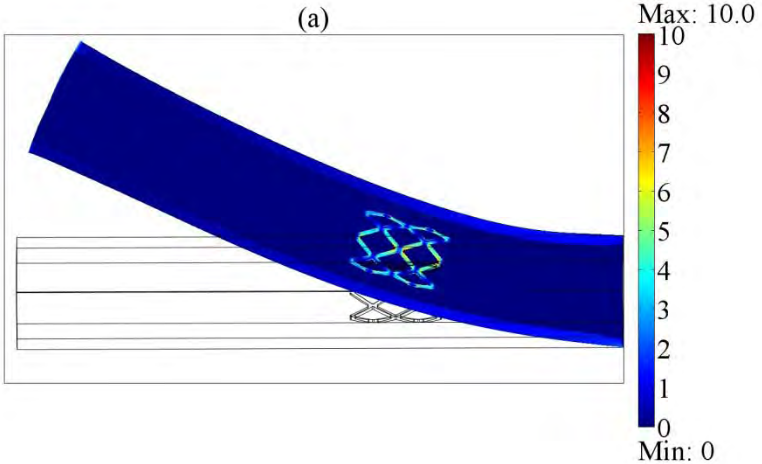


Von Mises stress

- BC-I
- 3 cm spacing
- 13 mm displacement
- Max stress: 13.58 MPa
- Average stress: 1.94 MPa

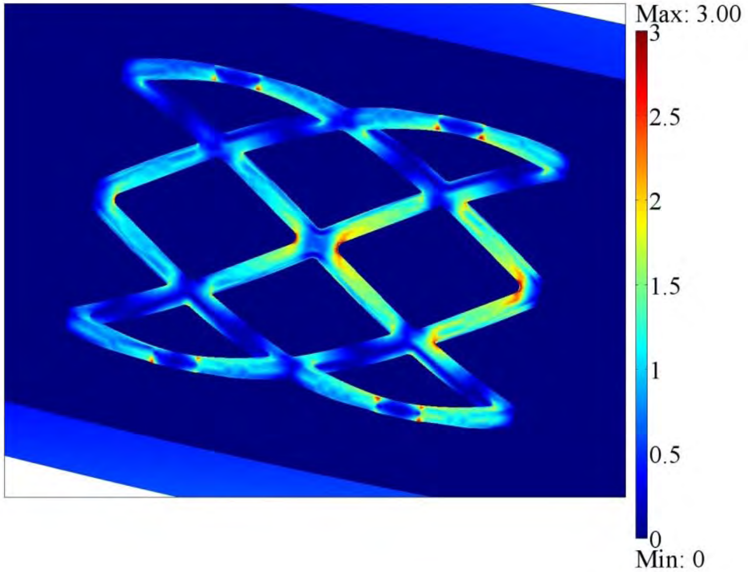


(a)

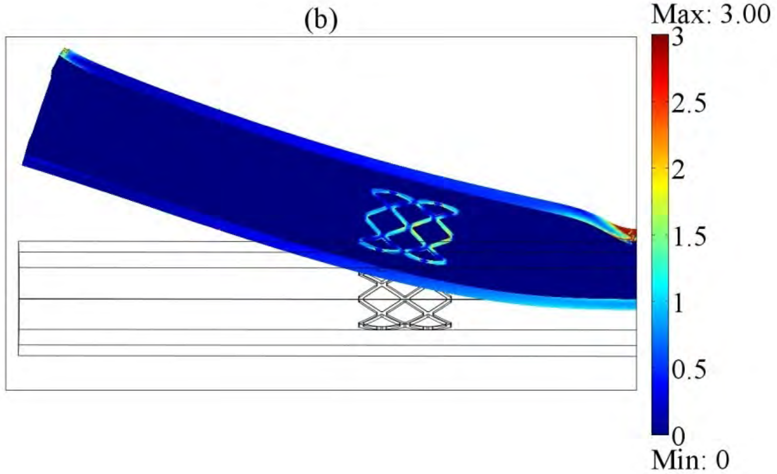


Von Mises stress

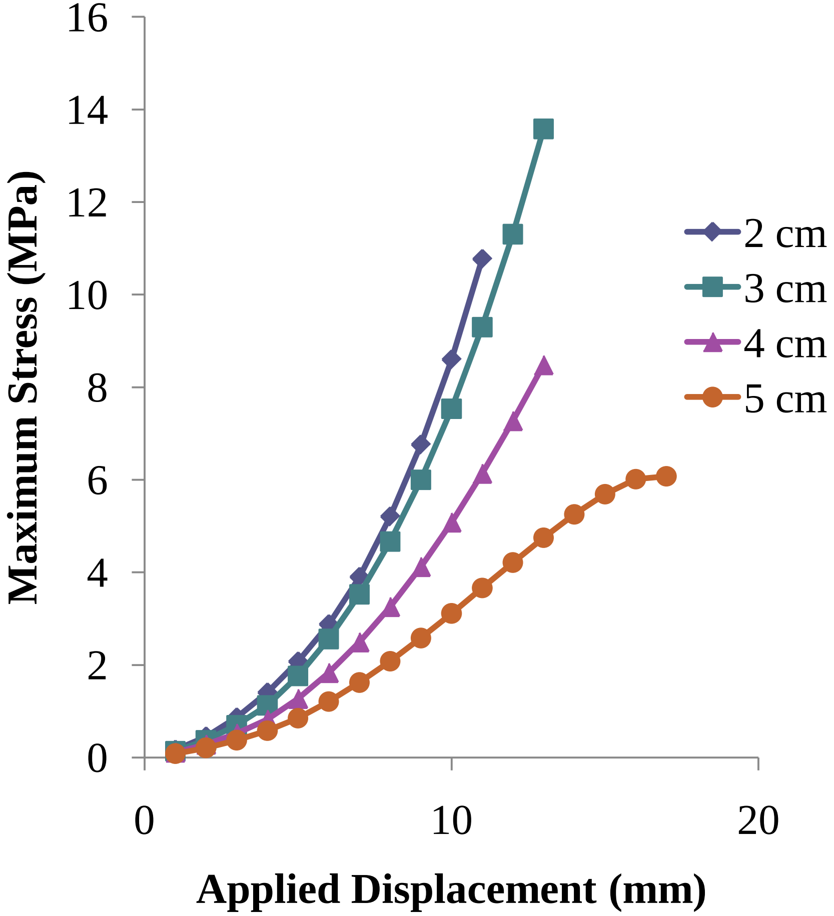
- BC-II
- 3 cm spacing
- 13 mm displacement
- Max stress: 4.05 MPa
- Average stress: 0.55 MPa

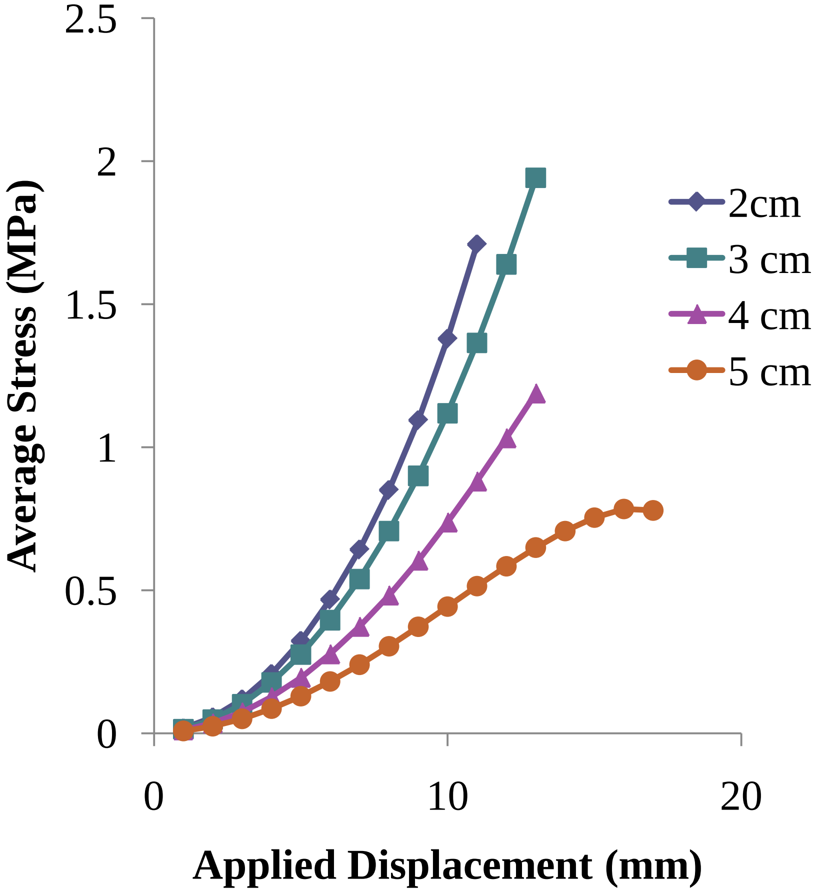


(b)

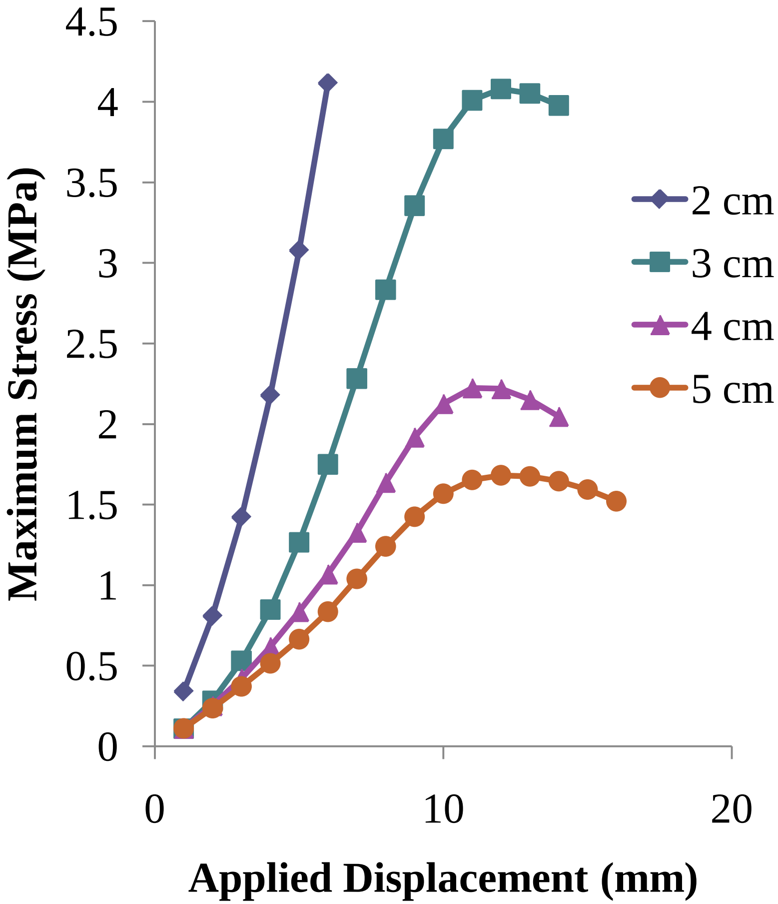


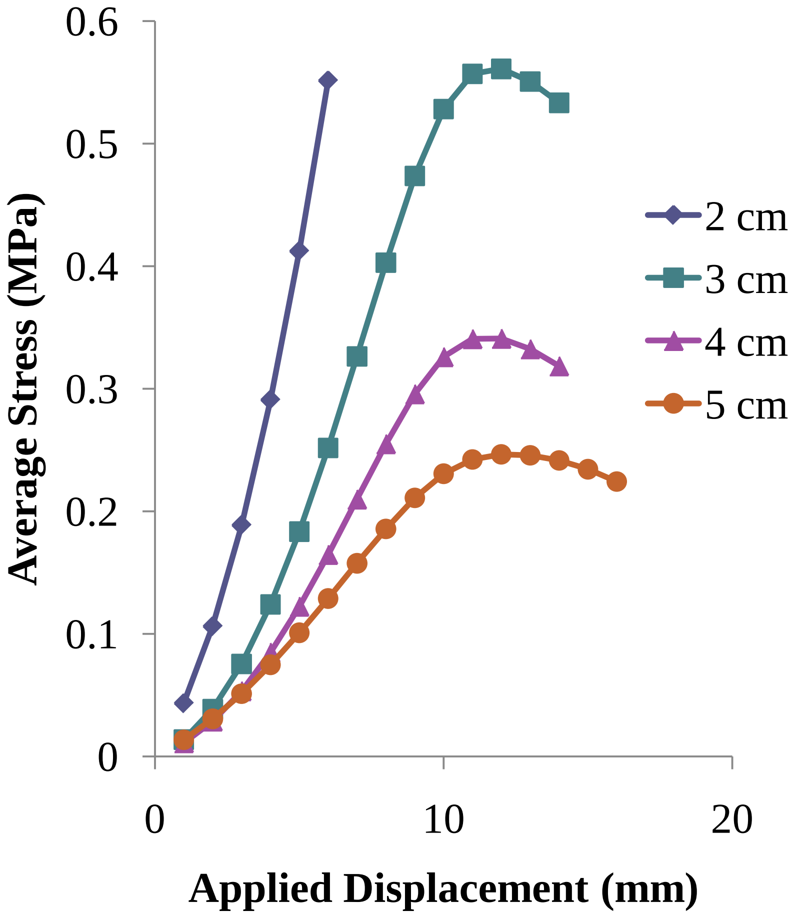
Results for segmented stent (BC-I)





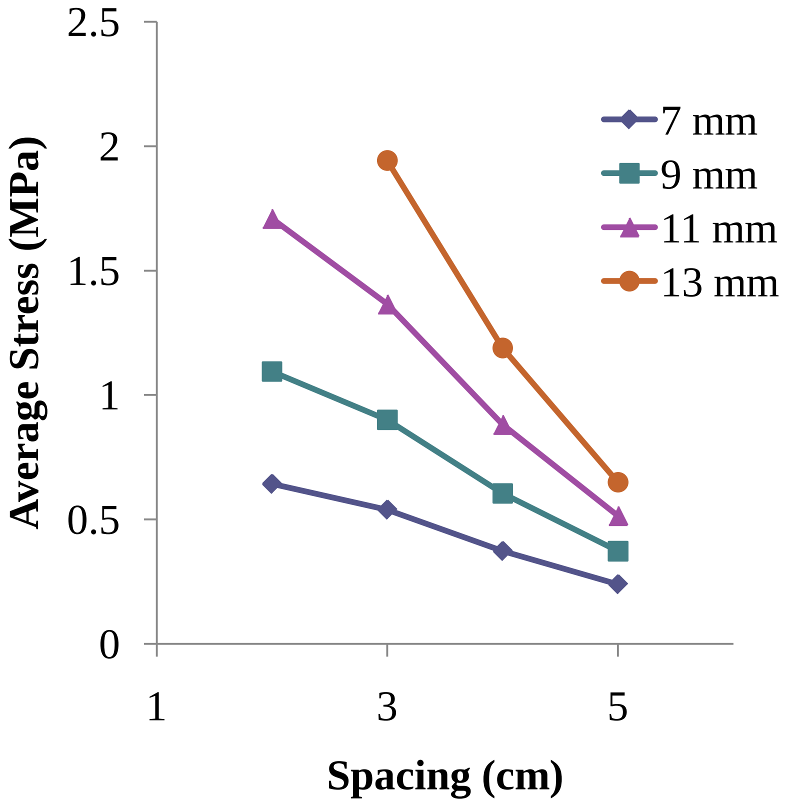
Results for segmented stent (BC-II)



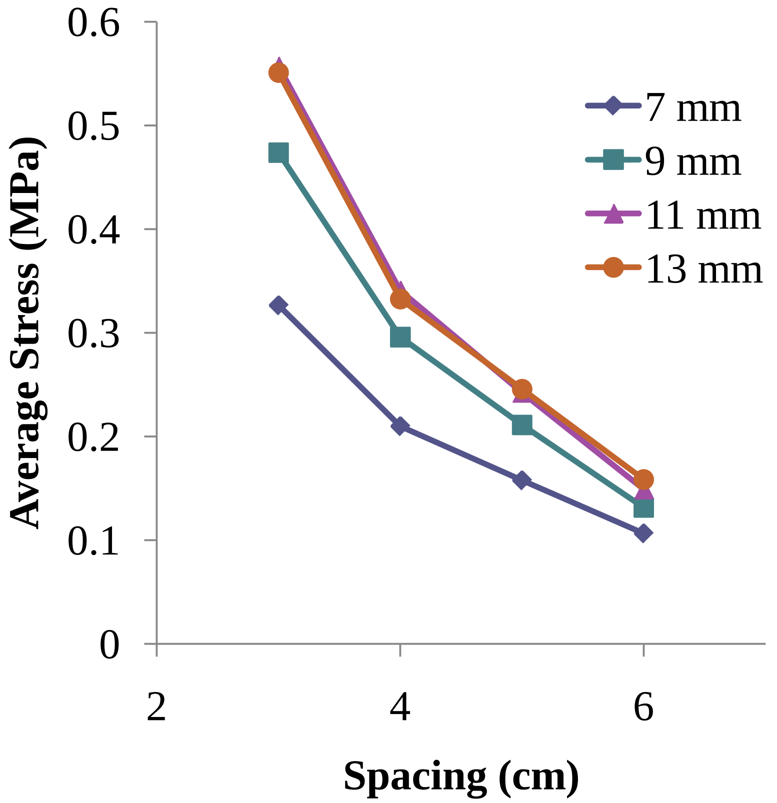


Effects of stent spacing

BC-I

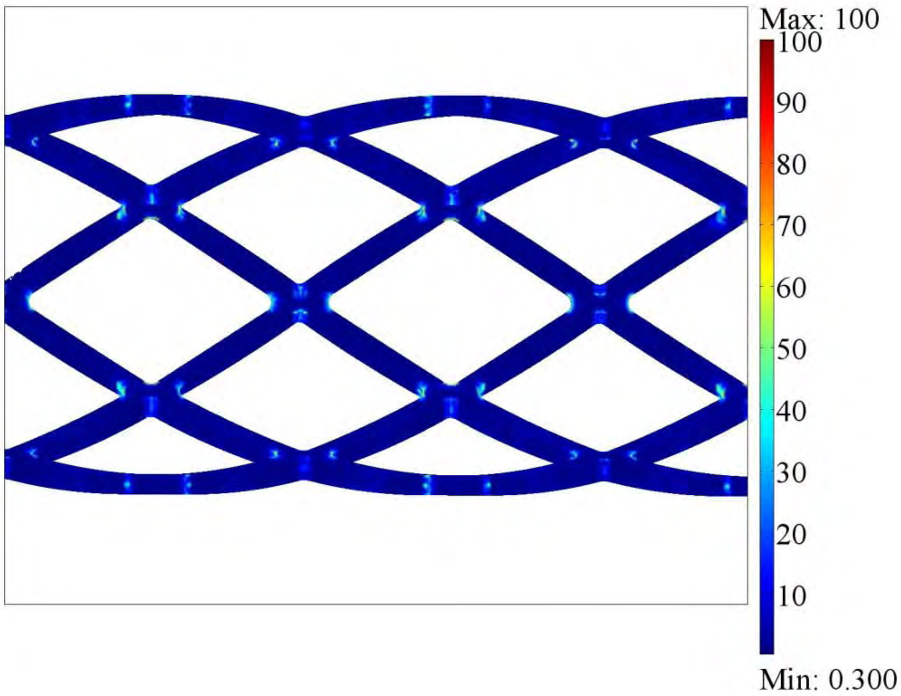


BC-II



Results for 48-mm stent

- Average stresses
  - 0.1 mm: 0.29 MPa
  - 0.25 mm: 0.72 MPa
  - 0.5 mm: 1.45 MPa
- Results for stent segments with 1-mm applied displacement
  - 1^{st} set of BC's: 0.02 MPa
  - 2^{nd} set of BC's: 0.04 MPa



Conclusions

- Segmented stent design provides lower stresses
- Future work
  - Vary mechanical properties of plaque
  - Use of more stent segments with variable spacing and stent length
  - Apply radial expansion

Acknowledgements

- Robert Giasolli from Innovasc
- Jim Greene, Graduate Student, UC Irvine

Questions?

References

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- [2] http://www.web-books.com/eLibrary/Medicine/Cardiovascular/Images/Athero.gif
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- [4] D.E. Kiousis, T.C. Gasser, G.A. Holzapfel, "A numerical model to study the interaction of vascular stents with human atherosclerotic lesions," *Annals of Biomedical Engineering*, **35**, 1857-1869 (2007).
- [5] S.A. Kock, J.V. Nygaard, N. Eldrup, E.T. Frund, A. Klaerke, W.P. Paaske, E. Falk, W.Y. Kim, "Mechanical stresses in carotid plaques using MRI-based fluid-structure interaction models," *Journal of Biomechanics*, **41**, 1651-1658 (2008).
- [6] W. Wu, M. Qi, X.P. Liu, D.Z. Yang, W.Q. Wang, "Delivery and release of nitinol stent in carotid artery and their interactions: A finite element analysis," *Journal of Biomechanics*, ***40***, 3034-3040 (2007).