DEPLOYMENT OF AN INTRAVASCULAR STENT IN CORONARY STENOTIC ARTERIES: A COMPUTATIONAL STUDY

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INTRODUCTION

Intravascular stents are small tube-like structures placed into stenotic arteries to restore blood flow perfusion to the downstream tissues [1]. If compared to angioplasty, stent higher efficiency is supported by randomized trials and clinical studies. Nevertheless, problems and difficulties remain, such as migrations, collapses, cloth formation, positioning difficulties (flexibility, trackability, etc…) and re-stenosis. The stent expansion includes large displacements and deformations, geometric and material non-linearity, which are difficult to properly simulate.

The purpose of this work is to study by means of the finite element method the effects of the expansion of a metallic stent on a stenotic coronary artery in terms of stresses and contact pressures.

MATERIALS AND METHODS

A three-dimensional model of the stent in its unexpanded configuration with the coronary artery and a atherosclerotic plaque is depicted in Fig. 1. The stent is assumed to be a tube with rectangular slots on its surface. The stent, resembling the classical Palmaz-Schatz model, has a length of 16 mm and has 5 slots in the longitudinal direction and 12 in the circumferential direction, with an outer diameter of 1.1 mm. The stent is assumed to be made of 316LN stainless steel. The inelastic constitutive response is described through a Von Mises-Hill plasticity model with cinematic hardening. Young modulus is 196 GPa, the Poisson ratio 0.3, the yield stress 205 MPa, the limit stress 515 MPa [2,3]. The material hardening during the crimping is taken into account by lowering the tensile stress-strain curve. The materials of the arterial wall and the plaque were modeled using hyperelastic constitutive equations able to reproduce the non-linear stress-strain relationship as found by Salunke *et al*. [4] in human arteries. Two different atherosclerotic plaques (model A and model B) with increasing stiffness were reproduced. The properties of the artery is the same for the two models studied. Figure 2 reports the adopted curves.

A large deformation analysis is performed using the commercial code ABAQUS (Hibbit Karlsson & Sorenses, Inc., Pawtucket, RI, USA). The stent is loaded by an internal uniform radial pressure (P) (inflation) till the value of 2 MPa. The artery and the plaque are pre-stretched and loaded with a uniform pressure of 100 mmHg before the stent expansion. 10-node tetrahedral elements are used in all the analyses. Due to the symmetry only one twelfth of the whole model (Fig.1) is studied with a total number of nodes of 8835 and a number of element equal to 4471 (1124 for the stent, 1259 for the plaque and 2088 for the artery). Stresses and radial displacements were recorded for the three different situations studied.

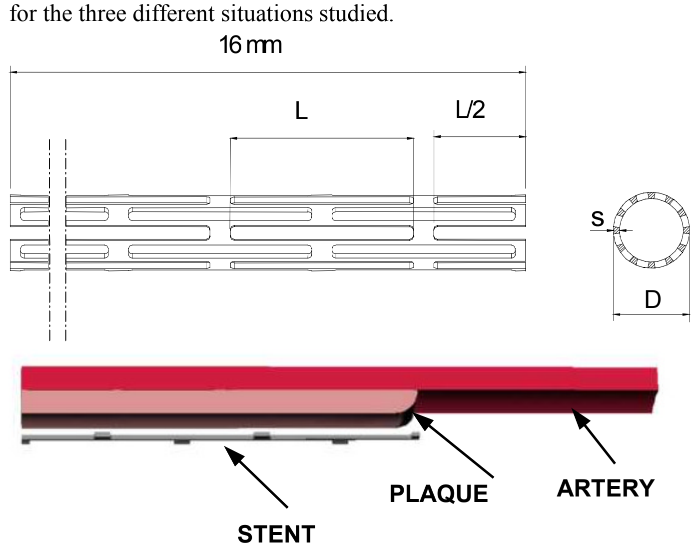

Figure 1. Geometry with the main dimension of the stent and a twelfth of the whole unexpanded model of the stent strut with the correspondent portion of stenotic coronary artery. L: length of the slot, s: thickness, D: outer diameter.

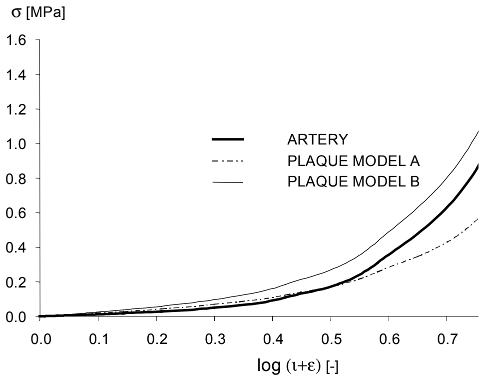

Figure 2. Stress-strain curves for the artery (bold) and the two models of plaque with increasing stiffness.

RESULTS

Figure 3 reports the undeformed and deformed meshes for the model B after the application of 2 MPa upon the internal stent surface. Figure 4 shows the Von Mises stresses in the artery and the plaque of model B. The stress are concentrated in the contact areas of the plaque with the stent. Small stresses are induced in the arterial wall. As regards the absolute values of the stresses, the stiffer the plaque (model B), the higher is the pressure necessary to reach the same inner expanded diameter (Table 1 and Fig. 5).

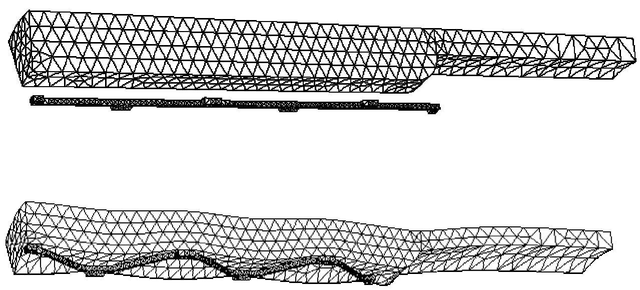

Figure 3. Undeformed (top) and deformed (bottom) mesh configurations of the stented artery after the expansion for model B.

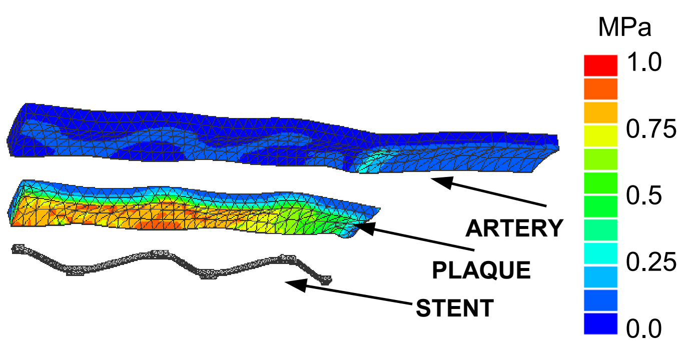

Figure 4. Von Mises stresses in the artery and in the plaque in an exploded representation of the model B. The stent is represented without reporting the Von Mises stress which are grater of two orders of magnitude (about 350-400 MPa).

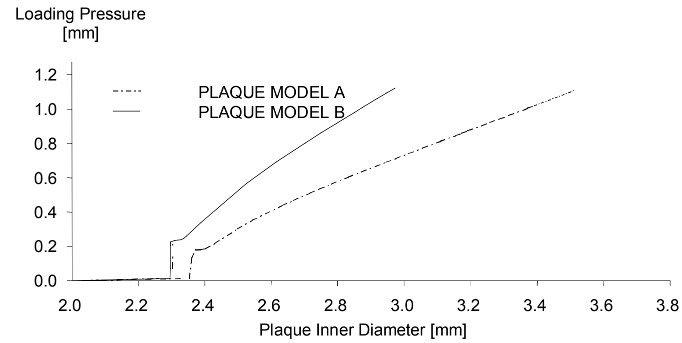

Figure 5. Pressure-inner expanded diameter curve for the two models adopted.

Table 1. Maximum Von Mises stresses in the artery and in the plaque and the inner expanded diameter of the plaque at the pressure of 1.1 MPa.

	Max stress [MPa]		Diameter after expansion [mm]
	artery	plaque	
Model A	0.259	1.728	3.552
Model B	0.189	0.967	2.976

CONCLUSIONS

A finite element analysis similar to the one herewith proposed could help in understanding vessel response to stent deployment. Different models of intravascular stents could be modeled and compared either terms of design (*i.e.* number of rings, links, …) and of constitutive materials (*i.e.* metal *vs*. shape memory alloy)

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REFERENCES

1. Dotter, C. T., 1969, "Transluminally-placed coil spring end arterial tube grafts, long-term patency in canine popliteal artery". Investigative Radiology, 4, pp. 329-332.
2. Auricchio, F., Di Loreto, M., Sacco, E., 2001, "Finite-Element analysis of a stenotic artery revascularization through a stent insertion". Computer Methods in Biomechanics and Biomedical Engineering, 4, pp. 249-263.
3. Migliavacca, F., Petrini, L., Colombo, M., Auricchio, F., Pietrabissa, R, 2002, 'Mechanical behavior of coronary stents investigated through the finite element method' Journal of Biomechanics, 35, pp. 803-811.
4. Salunke, N. V., Topleski, L. D. T., Humprey, J. D., Mergner, W. J., 2001, "Compressive stress-relaxation of human atherosclerotic plaque" Journal of Biomedical Material Research, 33, pp. 236-241.