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Numerical Stress and Deformation Analysis of a Coronary Stent Inserted into a Stenoted Artery

Angelica Enkelhardt, Cristian-Sorin Neş, Nicolae Faur

Universitatea "Politehnica" Timişoara, Bd. Mihai Viteazu nr.1, Timişoara, Romania
e-mail: angelica.enkelhardt@yahoo.de

Abstract

Stent implants offer the optimal solution in treating arterial stenosis and aneurisms. The angioplasty is a relative simple procedure and has several strong points: high success rate, short convalescence period with almost no complications and low const compared to classic surgical procedures. Stress and deformation analysis of the stent implant is an important tool in improving the design, choosing the appropriate materials and life time evaluation. ANSYS 11 finite element analysis program was used to determine the stress and deformation distributions in a Nitinol self-expandable stent, inserted in a 60% stenosed artery. The results showed the existence of high levels of stress, locally exceeding the material's yield limit. The stress was higher at the tip of the wire winding of the peripheral segments

Key words: *coronary stent, plaque, stress, deformation, numerical analysis.*

Introduction

In recent years, stent grafts proved to be the optimal solution in treating arterial stenosis and arterial aneurysms. The relative simple procedure (angioplasty) has produced a large interest inside the medical community, due to the high success rate, short and complications-free convalescence period and reduced costs compared to classical invasive surgery. As well, the patient's lifestyle does not have to change drastically therefore the procedure meets general acceptance amongst the patients.

A vascular stent is a small metallic tube inserted in the artery in the narrowed zone; it behaves like an artificial support for the blood vessel. There are two major stent types: self-expandable stents made of shape memory materials (nitinol, polymers) and balloon-expandable stents. The self-expandable stents have the decisive advantages of superior endurance and simple installation procedure.

The stent this paper analyses consists in 12 interconnected rings made of nitinol wires (Fig.1). The tube is 22.4 millimeters long, has a diameter of 8.3 millimeters and is

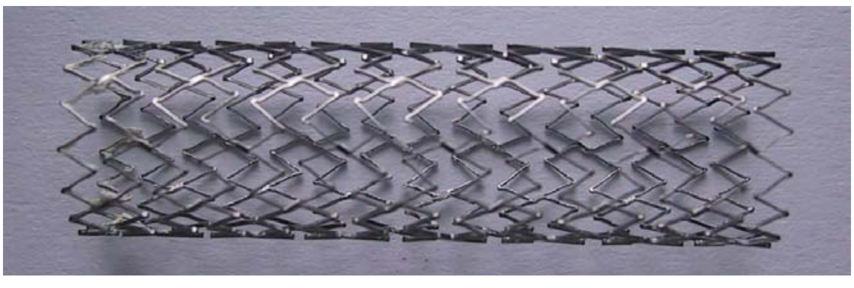

Fig.1. Nitinol self-expandable stent

dedicated to stenosis-related applications.

Nes et al. [1] and Marrey et al. [2] performed fracture analysis on these implants, while Liang et al. [3], Chua et al. [4], Takashima et al [5] studied the interaction between the stent and the plaque-covered artery.

Numerical modelling of the coronary stent-blood vessel interaction provides room for design improvements as well as clear indications about the limits of this procedure-s applicability.

Model Description

The model consists of the metallic stent, plaque and artery (Fig.2), imported in ANSYS 11 FEA program. The plaque thickness simulates the conditions of maximal stenosis for stent implants (60%). Provided that these implants use the austenitic phase of the nitinol alloy, the stent material can be considered linear elastic. The plaque and the artery wall could be as well modeled as linear-behaving materials [4]. The material properties are listed in Table 1.

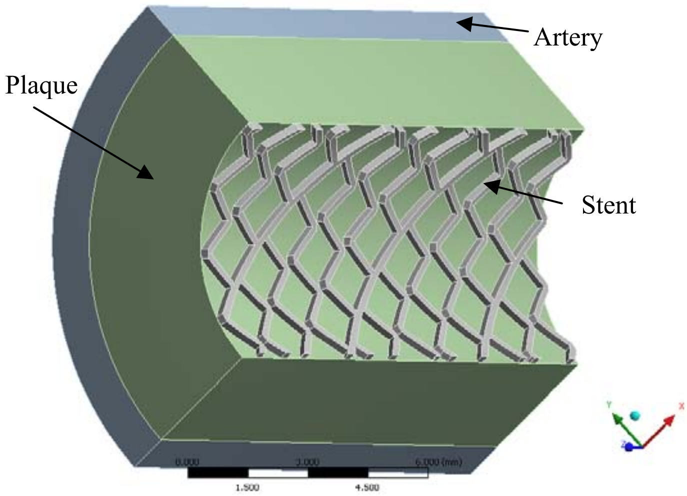

Fig.2. The geometrical model

Table 1. Material properties used in simulation

Parameter	Stent [www.euroflex-gmbh.de]	Plaque Chua et al. [4]	Artery Chua et al. [4]
Elastic modulus	48 GPa	0.00219 GPa	0.00175 GPa
Poisson's ratio	0.33	0.499	0.499

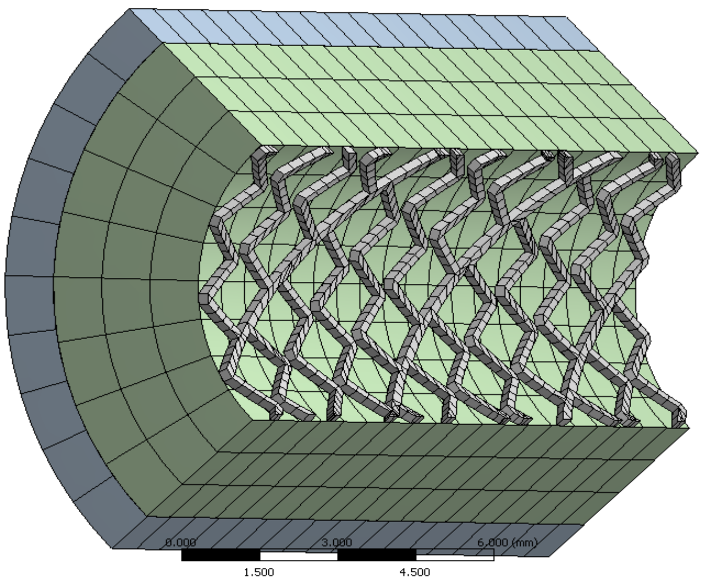

Fig.3. The meshed model

On the inner surface of the stent was applied a pressure of 2.5 MPa. According to Lally et al. [6], this is the maximal pressure produced by a 60% stenoted blood vessel on an arterial stent. The model contains 1142 elements and 9631 nodes (Fig.3).

Results

The stress distribution (von Mises equivalent stress) is printed in Fig. 4. The highest stresses are located at the end of the tube. Therefore, one can conclude that the stent must be longer than the stenoted area. The effect of these elevated stresses can be the occurrence of blood vessel damage or breaking of the alloy wire. Although the rated tensile stress of nitinol is of approximately 1300 MPa, local stresses exceed the yield stress and can result in the malfunction of the implant.

The deformation distribution (Fig. 5) is similar with the stress distribution. Furthermore, it shows that a large amount of deformation is absorbed by the plaque. This further shows that the effect of the implant is greater at the ends of the tube and smaller in the middle. From a medical point of view, this situation is not desirable, because this variation of the vessel's diameter increases the chances of restenosis. Barrel-shaped stents or cylindrical stents with variable wire diameter would behave better, but they are more difficult to fabricate.

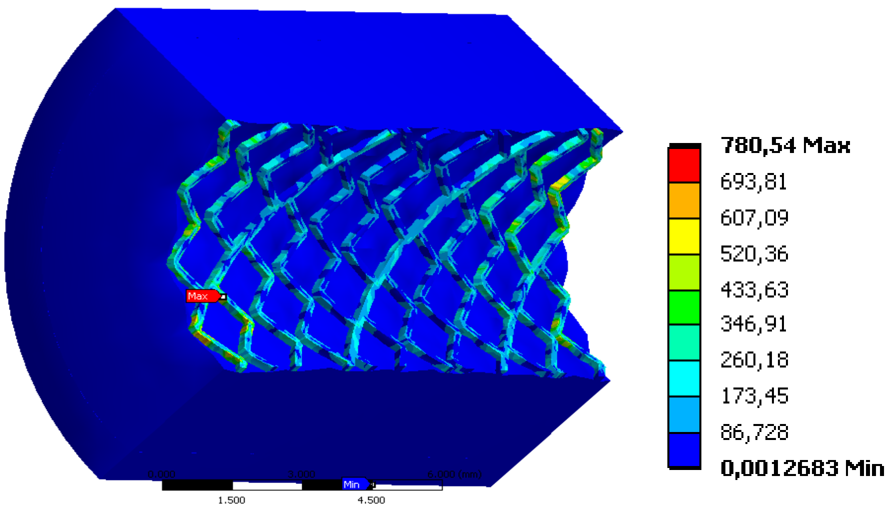

Fig. 4. The von Mises stress distribution [MPa]

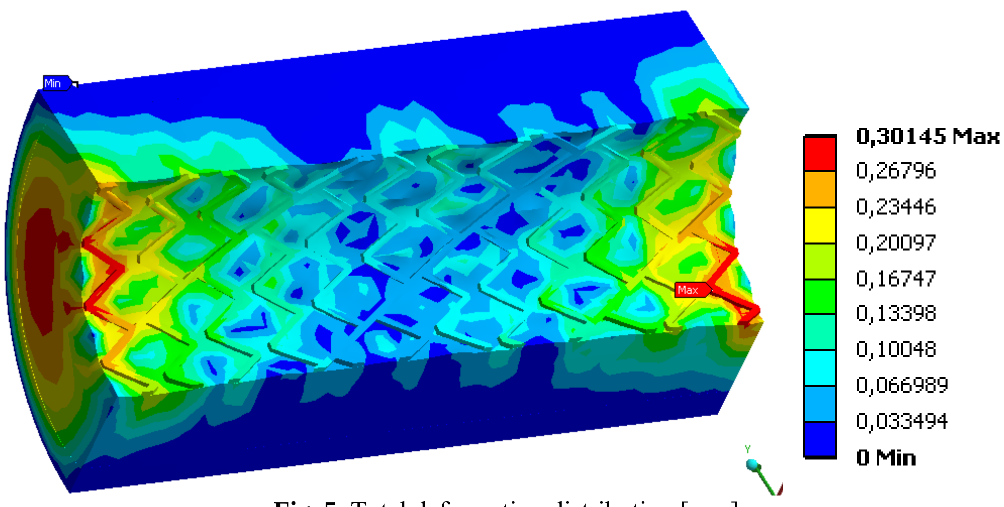

Fig. 5. Total deformation distribution [mm]

Conclusions

1. The length of the stent tube must exceed the length of the stenoted area.
2. The stenosis rate determines the stress and deformation levels.
3. For a 60% stenoted artery, the stresses induced into the implant locally exceed the yield limit of the material.
4. The stress distribution shows increased values at the ends of the tube.
5. The deformation produced by the stent increases towards the ends of the tube.

References

1. Neş, C.S., Enkelhardt, A., Faur, N., Birlan, A. – Numerical Stress Intensity Factors Determination for Fabrication Defects in Coronary, *Key Engineering Materials*, Vol. 488-489, 2012, pp. 718-721.
2. Marrey, R.V., Burgermeister, R., Grishaber, R.B., Ritchie, R.O. – Fatigue and life prediction for cobalt-chromium stents: A fracture mechanics analysis, *Biomaterials*, Vol. 27, 2006, pp. 1988-2000.
3. Liang, D.K., Yang, D.Z., Qi, M., Wang, W.Q. – Finite element analysis of the implantation of a balloon-expandable stent in a stenosed artery, *International Journal of Cardiology*, Vol. 104, 2005, pp. 314-318.
4. Chua, D.S.N., MacDonald, B.J., Hashmi, M.S.J. – Finite element simulation of slotted tube (stent) with the presence of plaque and artery by balloon expansion, *Journal of Material Processing Technology*, Vol. 155-156, 2004, pp. 1772-1779.
5. Takashima, K., Kitou, T., Mori, K., Ikeuchi, K. – Simulation and experimental observation of contact conditions between stents and artery models, *Medical Engineering & Physics*, Vol. 29, 2007, pp. 326-335.
6. Lally, C., Dolan, F., Prendergast P.J. – Cardiovascular stent design and vessel stresses: a finite element analysis, *Journal of Biomechanics*, Vol. 38, 2005, pp. 1574-1581.

Analiza numerică a stării de tensiuni şi deformaţii a unui stent coronarian inserat într-o arteră stenozată

Rezumat

Implanturile de tip stent s-au dovedit a fi soluţia optimă în tratarea stenozelor arteriale şi anevrismelor. Angioplastia este o procedură relativ simplă având ca principale atuuri, o rată ridicată de reuşită, perioadă de convalescenţă scurtă şi lipsită de complicaţii pentru pacient şi costuri reduse comparativ cu intervenţiile chirurgicale clasice pentru remedierea aceloraşi probleme. Analiza stării de tensiune şi deformaţie a stentului este deosebit de importantă în vederea optimizării geometriei, a alegerii materialelor şi a evaluării duratei de viaţă a implantului. Utilizând pachetul software ANSYS 11, s-a putut determina pe cale numerică, distribuţia tensiunilor şi deformaţiile apărute la implantarea unui stent autoexpandabil din Nitinol într-o arteră obturată în proporţie de 60%. Rezultatele au arătat existenţa unor tensiuni ridicate, apropiate de limita de curgere a fazei austenitice. De asemenea, s-a putut observa că tensiunile cele mai mari sunt situate la vârful impletiturii din sârmă, iar cele mai solicitate segmente sunt cele periferice.