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MODEL OF MECHANICAL PROPERTIES OF NITINOL STENT

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Abstract − Stents and stentgrafts are used in last years very often, especially for treatment of stenosis and aneurisma of vessels. But there are some possible risks, when stents are applicated. The stent can migrate inside a vessel, it can be leaky or deformed.

To investigate interaction between stent and a wall of vessel we must have model of mechanical properties of the vessel and of the stent. As to the vessels a lot of models were designed [1], [2] but as to the stents, the situation is worse. So we have decided to try to develop our own model based on the knowledge of material parameters of nitinol, of the geometry of stent and of its segments.

Keywords: stent, model, nitinol.

1. INTRODUCTION

Intravascular stents (Fig. 1.) are small tube-like structures placed into stenotic arteries to restore blood flow perfusion to the downstream tissues. Stent implantation is a minimally invasive technique for restoring the luminal patency of stenosed or occluded arteries. The stent itself is an intravascular scaffolding, most commonly composed of thin spiral or mesh-shaped metal or polymer structure which support the arterial wall from inside. Several types of stents are available exhibiting a wide difference in their mechanical properties. These differences depend on the design of stent and on material and technology used too. A brief review leads us to distinguish two types of metal endoprostheses: mesh and monofilament metallic balloon-expandable stents (expanded by inflation of an angioplasty balloon) and elastic and memory shape self-expandable stents.

Fig. 1. The stent.

The first implanted stent was described by Dotter in 1969 to treat arterial shrinkage. The clinical routine implantation began in the 1990s to improve the limitations of balloon angioplasty. Nevertheless, problems and difficulties remain, such as migrations, collapses, cloth formations or positioning difficulties.

Because different typologies of stents are available on the market, the importance for the operator to know the different physical properties of the stent selected to treat a specific lesion is obvious.

In spite of intravascular stents are routinely and successfully used, further research and developments are still necessary, in particular to improve the design and to reduce the long-term failure.

We can find a lot of literature about stents over the last about 10 years, but their mechanical properties have received little attention. That is truth, that during last few years we can find articles about modelling the mechanical properties of stent by means of finite elements method (FEM). And really few articles is about real measuring of mechanical properties of stents, in spite of a lot of publications is underlying the necessity of such data.

Although FEM is a methodology well known, it is worthwhile remembering that the reliability of the results clearly depends on the assumptions and hypotheses adopted in the analysis. We know that there are non-linearities (geometrical and material), but in certain range of the elastic deformation the pressure-strain curve is obviously linear [3]. We have tried to develop our own model of mechanical properties of stent based on theory of elasticity and to identify the parameters, which influence the final mechanical properties of a stent. It could show us also, which parameters and how should be changed to produce a stent with required mechanical properties.

2. MODEL OF MECHANICAL PROPERTIES OF NITINOL STENT

We have decided to try to create model of nitinol stent. We have chosen the nitinol self-expandable stent with very simple mesh structure. We have substituted its real structure by the chain of rings (Fig.2.).

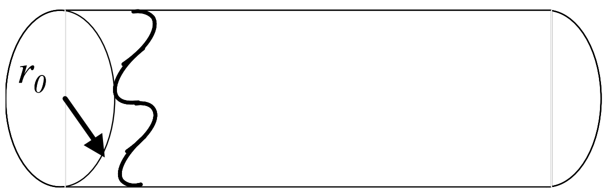

Fig. 2. The simplified model of stent.

Every ring consists of several semicircles with radius r_1 (Fig. 3).

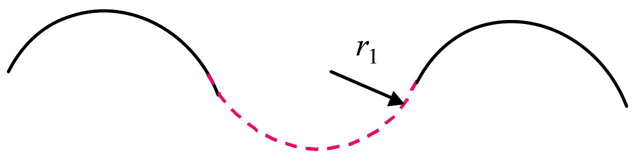

Fig. 3. The set of semicircles.

If the stent is deformed by outside pressure, the elements are deformed too (Fig. 4.).

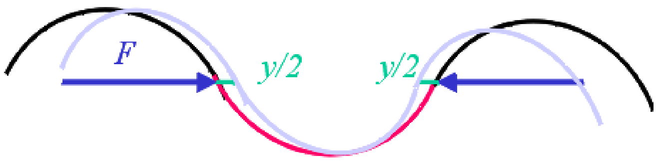

Fig. 4. Deformation of one element.

The deformation of one ring can be described as a relative change of its circumference $\varepsilon = (l_0 - l)/l_0$. If r_1 is radius of semicircle, r_0 is the idle radius of the whole stent and y is displacement of the and of one semicircle, we can express the absolute change of the circumference of the ring as product ny and $l_0 = 2\pi r_0$. Then the relative change is

$$\varepsilon = \frac{ny}{2\pi r_0}, \qquad (1)$$

where n is number of semicircles. Now we can use Hooke law:

$$\sigma = E'\varepsilon. \qquad (2)$$

Because $\sigma = F/S$, where F is the impact force and S is surface of one ring, we can find equation

$$\frac{F}{S} = E'\frac{ny}{2\pi r_0}. \qquad (3)$$

The area of the surface of one ring is $S = 2\pi r 2r_1$ and relation between r and r_1 is

$$r_1 = \pi r_0 / n. \qquad (4)$$

Thus, we can express the relation between the impact force and deviation of one semicircle by means of equation

$$F = 2E'\pi r_0 y. \qquad (5)$$

Because we know the mechanical properties of nitinol and the geometrical parameters of stent, it is possible to find the same relation by means of theory of elasticity. We can regard the semicircle as the rod with the circular section and with the length $l_1 = \pi r_1$. This rod is bended by the impact force F. By means of theory of elasticity [3] we can find relation between the force and displacement of the end of the rod:

$$F = \frac{48EJ}{l_1^3}. \qquad (6)$$

Using (4) we can find:

$$F = \frac{48En^3J}{\pi^6 r_0^3}. \qquad (7)$$

Here E is Young modulus of elasticity (Pa), J is cross-sectional moment of inertia. This moment depends only on the diameter d of the rod (wire) [3]:

$$J = \frac{\pi d^4}{64}. \qquad (8)$$

Thus the deformation can be described by means of equation

$$F = \frac{3Ed^4n^3}{4\pi^5 r_0^3}y. \qquad (9)$$

Where F is force (N), y is displacement (m), d is diameter of wire (m), r_0 is radius of stent, E is Young modulus of elasticity (Pa). Deformation of stent can be described by the relative change of circumference of the stent. Its value is determined by impact force and by stent stiffness. In the steady state the impact pressure is in equilibrium with tension of elastic elements. By comparing (5) and (9) we can find equation

$$E' = \frac{3En^3d^4}{8\pi^6 r_0^4}, \qquad (10)$$

where E' is Young modulus of elasticity of the stent (Pa), which describes the stiffness of the stent. To see how the stiffness of the stent depends on the idle radius of one semicircle we can use (4):

$$E' = \frac{3Ed^4}{8\pi^2 n r_1^4}. \qquad (11)$$

3. DISCUSSION

The main task of this work was to determine material and geometrical parameters, which can influence the final mechanical properties of the stent. Our approach is based on a lot of simplifications. For example the length (circumference) of the single semicircle is calculated only in plane but it is curved also in space along the circumference of the stent. Or an effect of junctions between neighbouring rings is neglected. This model cannot be used for simulating of behaviour of a real stent, because it is not able to describe such problems as the fatigue or collapsing of the stent. On the opposite site, when stents are applied, they perform under normal conditions in the linear part of their stress-strain curve. But it could be appropriate for more qualitative then quantitative description of mechanical properties of stents in this mode of performance.

4. CONCLUSIONS

In the certain range of deformation the relation between the impact outside pressure and deformation is linear [4]. It is obvious (11), that the mechanical properties of stent are very sensitive to the radius of the used wire, to number of elements and their radius. In other words, mechanical properties of stents depend essentially on its geometrical design. When the stent is applied in the artery, its diameter is smaller then it is in the idle state. It means, that with the increasing diameter the force impacting the artery wall is decreasing, what must be considered during its implantation.

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