# Biomechanical Analysis of Cardiological Guidewire Geometry Forming

**Witold Walke and Joanna Przondziono**

**Abstract** The chapter presents strength analysis of selected structural forms of currently used cardiologic guidewires for introduction of endocavital electrodes. The assumptions that were made in performed biomechanical analyses considered both, the technique of treatment as well as various shapes of guidewires. Calculations were made for two alternative geometrical forms: straight and conical, made of X10CrNi18-8 steel used for medical products. Finite-element method was used for the analysis of FEM analysis enabled to obtain information about places featuring the highest effort of the material during pre-surgery premodeling. That kind of information is useful for proper selection of structure, mechanical properties of metallic biomaterial, and it is also very important for proper design of its geometry and formation of physical and chemical characteristics of the upper layer.

**Keywords** X10crni18-8 steel · Cardiologic guidewire · Biomechanical analysis · FEM

## 1 Introduction

An issue of significance in the process of functional characteristics of cardiologic guidewires formation is selection of mechanical features of metallic biomaterial as well as physical and chemical characteristics of the product. Formation of functional form is made on the ground of its properly selected biomechanical

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characteristics, determined with reference to treatment technique. It results from the necessity to lead the tip of guidewire to the respective place in blood and vascular system. Properly performed treatment shall result in its permanent deformation, which assures precise placement of implant or electrode [1–6]. Due to the fact that experimental determination of mutual interaction of guidewires and blood and vascular vessels in in vivo tests is difficult, researchers concentrate on virtual tests with application of computer mechanics, and in particular—finite-element method. Applicability of that method is connected with the adopted assumptions that should reflect anatomical and physiological conditions of blood and vascular system. Quality of guidewire characteristics is influenced most of all by premodeling, i.e. initial shaping of its geometry, performed by the doctor prior to treatment. Additional influence is also exerted by blood vessels in which guide wire is dislocated. Its biomechanical properties are connected among other things with the course of disease. Therefore, for proper determination of biomechanical characteristics of cardiologic guidewire, it is also necessary to prepare a numerical model of blood vessel. Only when a complex model: guidewire—blood vessel, has been prepared, taking into consideration physical and geometrical nonlinearity of guidewire and biomechanical properties of blood vessel, can proper selection of biomechanical characteristics of guidewire be made, including phenomena taking place in the course of the process [7, 8].

Many years of clinical practice enabled to determine geometrical features of various forms of guidewires that capacitate proper performance of cardiologic treatment. Not always were geometrical solutions as well as suggestions arising from location of implants supported with biomechanical analyses. Many studies also do not highlight the role of metallic biomaterial surface treatment, which is of great importance as far as corrosion resistance is concerned and which minimises blood coagulation. Explanation of those issues creates the conditions for optimum formation of functional properties, so optimum geometrical features of guidewires, spatial configuration and also their mechanical properties [9].

Against the background of unsolved problems, the chapter focused on biomechanical evaluation of the system: guidewire—blood vessel, with assumed and clinically recommended geometrical features. Properties of biomaterial were determined on the ground of biomechanical analysis.

Biomechanical analysis was made in order to determine the condition of stress, dislocation and strain of cardiologic guidewire used for electrode insertion. Obtained results are significant as far as the selection of structure and mechanical properties of metallic biomaterials used for guidewires is concerned. Due to the process of premodeling, condition of stresses initiated by plastic strain has a significant effect on the change of its geometrical features. Values of stresses that takes place in various parts of guidewire depending on deflection angle are crucial for proper design of its geometry, work hardening of biomaterial and formation of physical and chemical properties of the surface layer.

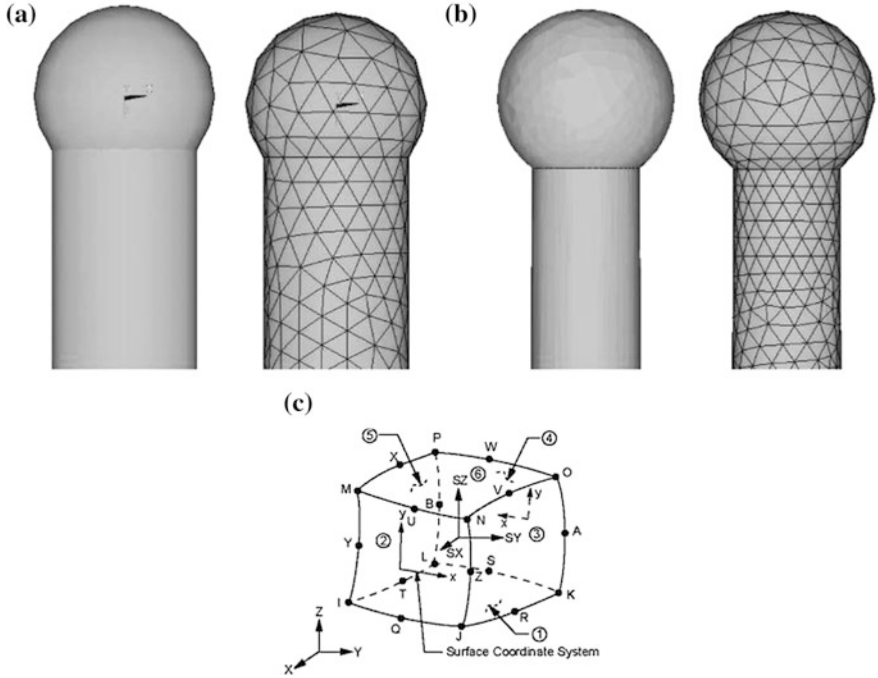


**Fig. 1** Calculation model of guidewire **a** straight, **b** conical, **c** element of SOLID186 type

## 2 Materials and Methods

The main purpose of the chapter was strength analysis of guidewire used for implantation of atrial or ventricular endocavital electrodes. Straight guidewire with diameter of d = 0.35 mm and conical ($\varphi = 5^{\circ}$) with ball tip and operating part length of l = 400 mm were selected for the analysis.

Geometrical model of analysed structural form of guidewire was prepared with application of Inventor software. Both, its geometrical features and typical structural features which distinguish it from other forms of wire, were taken into consideration in preparation of guidewire model. Proper profile and shape of the tool tip were maintained—Fig. 1a and b.

For the purpose of performed analyses, premodeling was simulated in the form of the system of three rollers with diameter d = 5 mm. Thus, three supporting points of the tool were obtained—Fig. 2. Thus, suggested system enabled to apply variable angle and radius of bend.

On the ground of prepared geometrical models, a finite-element mesh was generated for calculations with application of FEM. Discretisation of models of both, wire and the three-roller model was made with application of a finite element of SOLID186 type—Fig. 1c.

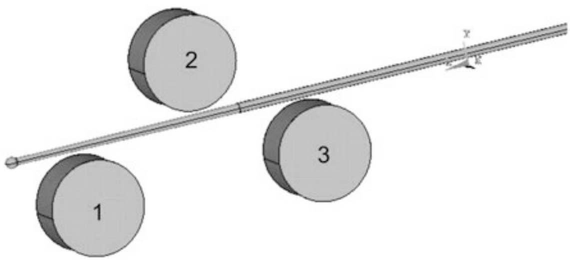


**Fig. 2** Model of three rollers system which enables to simulate differentiation of bend angle

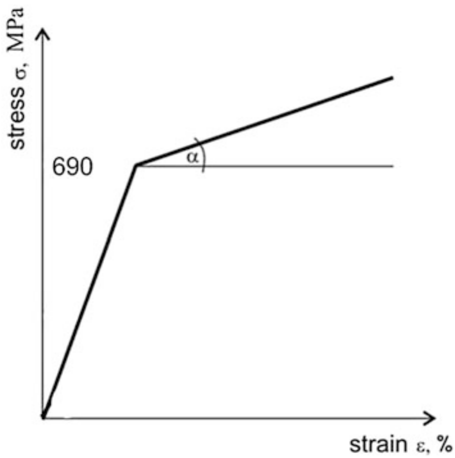


**Fig. 3** Bilinear characteristics for X10CrNi18-8 steel

The scope of performed analysis covered determination of the condition of stresses generated by the applied angular displacement at the tip of wire operating part within the range $\varphi = 0 \div 120°$ for two geometrical forms of guidewire—straight and conical.

For the purpose of calculations, material data corresponding to X10CrNi18-8 steel was adopted: E = 205,000 MPa, Poisson's ratio $\nu = 0.3$, $R_m = 1{,}010$ MPa, $R_{p0,2} = 690$ MPa. For the purpose of calculations, bilinear characteristics of elastic—plastic material with isotropic hardening were made—Fig. 3.

In order to make necessary calculations, it was indispensable to determine and establish initial and boundary conditions which would reflect phenomena taking place in the real system with proper precision. The following assumptions were made for the purpose of analysis:

- all nodes belonging to roller 2 were subject to relocation along the wire axis, which enabled positioning of places where wire was bent from its tip,
- deviation of guidewire tip within angular range of $\varphi = 1 \div 120°$ was accomplished through application of relocation of roller 3 in the direction perpendicular to the axis of the tool,
- contact between surfaces and edges of elements from the system, which enabled their mutual relocation, was defined.

**Table 1** Results of numerical analysis of straight and conical guidewire for differentiated values of angular displacement φ

| Type of guidewire | Reduced stresses $\sigma_{max}$, MPa | | | |
|---|---|---|---|---|
| | 30° | 60° | 90° | 120° |
| Straight | 252 | 504 | 726 | 859 |
| Conical | 272 | 545 | 755 | 907 |

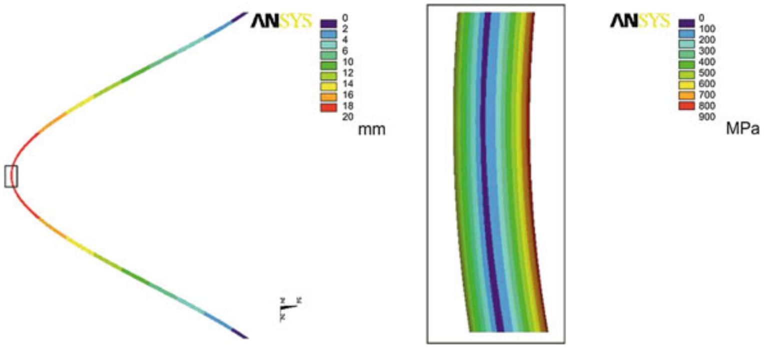


**Fig. 4** Results of strength analysis for bend angle φ = 120°: **a** state of dislocations u, mm, **b** state of reduced stresses $\sigma_{max}$, MPa

All values of strain and stress are values reduced in accordance with Huber—Mises theory.

## 3 Results and Discussion

The first stage of performed analyses included determination of the influence of angular displacement φ on distribution of stresses generated in the tip of operating part of guidewire for straight wire—Table 1. Exemplary distribution of dislocations and stresses, obtained as the result of bending at the angle of φ = 120°, is presented in Fig. 4.

Results of performed analyses show that the biggest values of reduced stresses for the respective values of angular displacement φ were observed in the area of direct impact of roller 2 on wire operating part. Maximum values of reduced stresses were located on the internal side of bent tool area.

The second stage of the analysis was aimed at determination of the influence of guidewire geometry changes (from straight to conical) on stresses generated during its bending. Obtained results showed little increase of maximum stress values for the same bend angles in relations to straight wires—Table 1. Maximum values of reduced stresses were located on the internal side of bent guidewire area, the same as for straight wires.

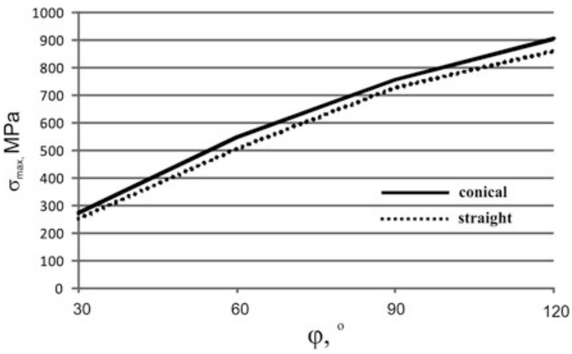


**Fig. 5** Relation between maximum reduced stresses as the function of angular displacement φ for straight and conical guidewire

Obtained results additionally created the ground for determination of biomechanical characteristics of two different forms of guidewire, specifying the relation between maximum reduced stresses generated in its operating part as the function of angular displacement for differentiated values of bend angle—Fig. 5.

## 4 Conclusions

One of the main problems connected with application of metallic cardiologic guidewires is the possibility of their initiation of coagulation process. The main way how to limit that unfavourable phenomenon is application of atrombogeneous coatings on its surface. These coatings should, apart from featuring good adhesion to metallic substrate, be susceptible to strain conditioned by pre-surgery forming of guidewire tip. Therefore, values of stresses and strain in the respective parts of guidewire, determined in the chapter, may be useful in order to form proper mechanical properties of the surface layers and create the ground for evaluation of their susceptibility to strain.

In conclusion, numerical analysis made with application of finite-element method for cardiologic guidewire showed that its production of X10CrNi18-8 steel, with the assumed for calculations set of mechanical properties, secure proper course of pre-surgery forming, and in consequence its permanent deformation at the required angle. Such conditions guarantee proper placement of electrodes in heart wall, which has a crucial impact on surgery efficiency.

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