789. Simulation and analysis of blood flow in bypass grafts with a cuff

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Abstract. In the paper the hemodynamics in the blood vessel and in the bypass graft is simulated and analyzed. A new construction of a bypass graft with a cuff is applied. The goal of the research is evaluation of influence of the ratio between the length and the height of the bypass graft cuff upon the structure of the blood flow and pathogenesis of the blood vessel. The results of the analysis indicate that blood flow velocity at a junction of the bypass graft and the blood vessel depends on the parameters of the cuff. The best results are obtained when the said ratio is 1.25 and 1.5 due to uneven distribution of pressure in the cuff. Choosing such parameters of a bypass cuff ensures better hemodynamics and absence of haemostasia, thus reducing a risk of formation of thrombi in the bypass graft and the blood vessel.

Keywords: blood vessels, bypass end-to-end, hemodynamics, FEM.

Introduction

Atherosclerosis is a dangerous cardiovascular disease that causes a reduction of the radius of a blood vessel and impeding or blocking the blood flow. It may cause cardiac infarction, if atherosclerotic plaques are formed in coronary arteries involved in blood supply to the heart. Anastomotic intimal hyperplasia (IH) and thrombosis are the most frequent failures in bypass surgery. There are two types of cuffs: end-to-end and end-to-side [1]. Scientific references indicate that the key goal of bypass surgery is a restoration of the normal blood flow. According to the general opinion, a failure of bypass surgery is caused by the local hemodynamics [2]. Although scientific literature provides several theories of IH formation, they are not clear [3]. If an autologous vein graft is not fit, a synthetic bypass of Teflon (PTFE) or Dacron may be used. These materials are the key synthetic materials suitable for a synthetic alternate. However, development of IH in the distal part takes place both in the autologous vein and the synthetic bypass [4]. Research of animal models in vivo showed that the distal part of the junction of the blood vessel and the bypass graft, in particular, the suture line, is mostly inclinable to IH formation [6, 7]. Numerical simulation is an ideal tool for a detailed examination of various parameters that influence IH formation [8, 9]. Many factors, such as the bypass geometry, angle of the bypass and its material, affect blood flow in the bypass.

The goals of the research are: to assess the impact of the geometrical parameters of bypass grafts with a cuff upon IH formation, to establish the impact of the ratio between the length and the height of the bypass cuff upon the structure of the blood flow and pathogenesis of the blood vessel. The scientific novelty of the work includes improvement of the geometry of the bypass graft and enhancement of its functionality. The developed model of a bypass graft with a cuff enables assessing various parameters that may impact formation of thrombi.

Methods

The geometry of the model is plane. Both the bypass and the cuff are autologous, i.e. the ones of the same body. It is supposed that walls of the blood vessel are rigid, i.e. they do not deform, the velocity at the walls equals zero, so friction is avoided, and the pressure in the distal outflow of the artery is equal to zero. The artery is considered a straight tube of a regular geometrical shape that is fully blocked. The model of the bypass graft with a cuff and the artery is provided in Fig. 1.

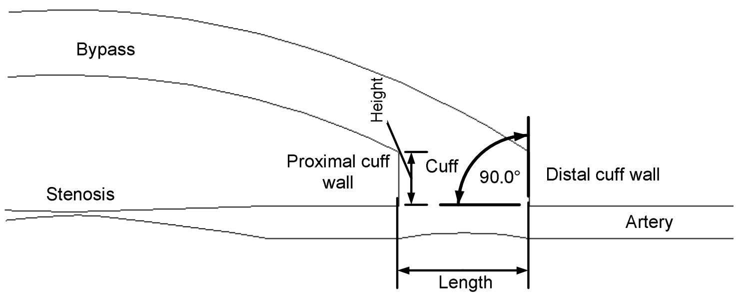

Fig. 1. The model of the bypass graft with a cuff and the artery

The cuff is of cylindrical shape and forms 90^{o} angle between the bypass graft and the artery. It is accepted that blood is Newtonian isothermal (i.e. its constant temperature equals to 37 ^{o}C) fluid. The blood flow is described by Navier – Stokes equation by applying the finite elements method (FEM) [10]:

$$\nabla \cdot v = 0;$$
$$\rho\left(\frac{\partial v}{\partial t} + v \cdot \nabla v\right) = -\nabla p + \mu \nabla^2 v, \tag{1}$$

where: v – vector of velocity of blood flow, p – pressure, t – time, ρ – blood density, μ – blood dynamic viscosity.

Blood density ρ = 1060 kg/m^3, blood dynamic viscosity μ = 0.0035 kg/ms. The cardiac cycle period T = 0.8 s. The cardiac rate is 75 beats per minute. The Reynolds number is calculated according to the following formula:

$$R_e = Dv\rho / \mu, \tag{2}$$

where: D – the diameter of the artery, mm.

The value of the Reynolds number depends on the input velocity and the diameter of the artery.

The examined ratios between the length and height of the bypass cuff are provided in Table 1.

Table 1. The ratio between the length and the height of the bypass cuff

Length, mm	Height, mm	Ratio
8	12	0.6
12	15	0.8
12	12	1
15	12	1.25
12	8	1.5
17	10	1.7

Software ANSYS is used for numerical simulation and analysis. It is a multifunctional program based on the finite elements method that enables to simulate and analyze the fluid dynamics and other physical processes.

Results of analysis

In Fig. 2 and Fig. 3, fragments of the results are presented for the case when the ratio between the length and height of the bypass cuff is 1.5. In the distal outflow, a weak vortex flow that rotates clockwise appears in the cuff. In such a model, the maximum velocity of 1.637 m/s is achieved in the distal outflow. The velocity of the vortex at the proximal wall of the cuff is approximately equal to 0.181 m/s. The velocity in the distal part of the cuff equals to 1.078 m/s. The pressure in the distal part of the cuff equals to 1288 Pa. The maximum pressure in the model equals to 1827 Pa.

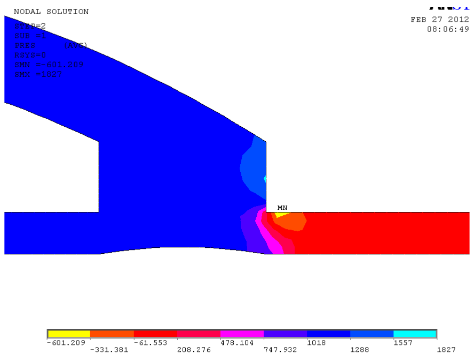

Fig. 2. Distribution of pressure in the bypass, when the ratio between the length and the height of the bypass cuff is 1.5

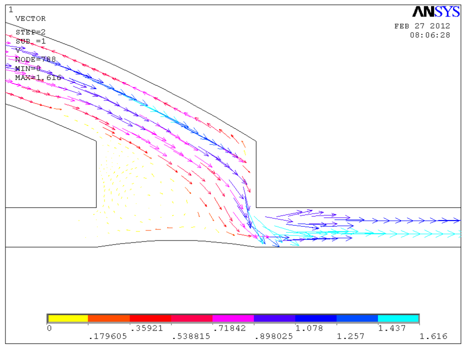

Fig. 3. The vector of velocity of blood flow

For comparison, fragments of the results when the ratio between the length and the height of the bypass cuff is 1 are provided in Fig. 4 and Fig. 5. The vortex flow formed in this model is stronger as compared to the model with the ratio of 1.5 (Figs. 2 and 3). Flow velocity at the proximal wall equals 0.228 m/s. The maximum velocity in the model is 2.06 m/s. Pressure in the distal cuff is uniform and equals 1117 Pa. The maximum pressure in the model equals 1889 Pa.

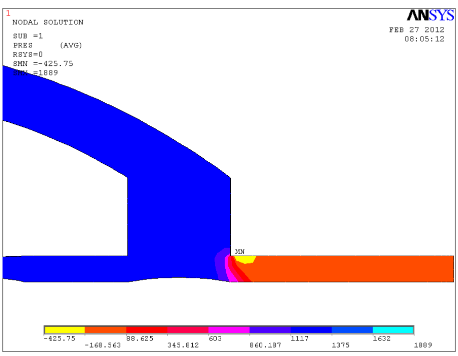

Fig. 4. Distribution of pressure in the bypass, when the ratio between the length and the height of the bypass cuff is 1

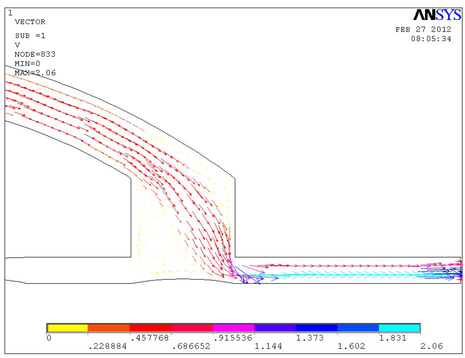

Fig. 5. The vectorial velocity of blood flow

Other models are analyzed in an analogous way. The obtained summarized results are provided in Figs. 5 and 6. The best results are obtained when the ratio is 1.25 and 1.5, because distribution of pressure in the cuff is uneven. So, in these cases, IH formation is impossible. In all other models, the distribution of pressure is even, so development of pathogenesis of blood vessels, i.e. IH, will appear earlier, thus resulting in a reduction of the bypass patency period.

Distribution of pressures and velocities is even enough; only at ratios 0.6 and 0.8, a sudden jump of pressure takes place and it impacts the geometry of the cuff, i.e. causes changes of its shape.

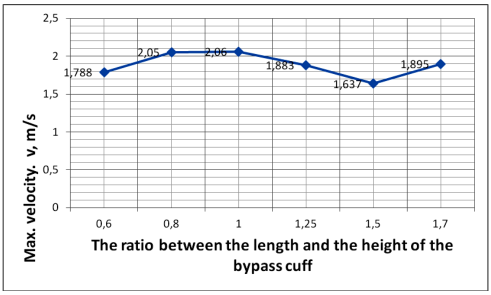

Fig. 6. Dependence of blood flow velocity on the ratio between the length and height of the bypass cuff

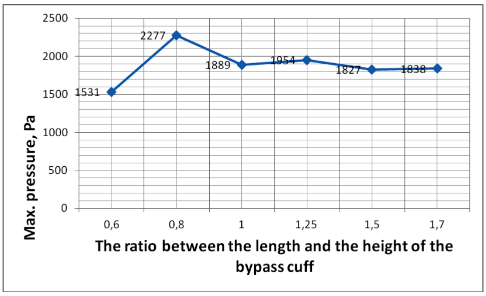

Fig. 7. Dependence of pressure in the bypass on the ratio between the length and the height of the bypass cuff

Conclusions

Computer models of a bypass graft with a cuff have been developed. In the calculations, the ratio between the length and the height of the bypass cuff was varied from 0.6 to 1.7. After blood flow simulations with finite elements method, it may be concluded that the best results are obtained when distribution of pressure in the cuff is uneven. Such a situation takes place when the ratio between the length and the height of the bypass cuff equals 1.25 and 1.5. These parameters of the bypass cuff will ensure better hemodynamics and absence of haemostasia, thus reducing a risk of formation of thrombi in the bypass and blood vessel as well as IH formation and increasing the bypass patency period.

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