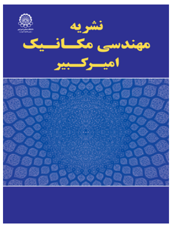

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 665-668
DOI: 10.22060/mej.2020.17508.6605

Comparison of Natural and Synthetic Carotid Arteries in the Normal and Occluded Cases Considering the Effect of Blood on Elastic Wall of Artery

H. Bagheri-Esfeh[1,*], S. Shanehsaz[2]

[1] Department of Mechanical Engineering, Shahreza Campus, University of Isfahan, Iran
[2] Department of Mechanical Engineering, Isfahan University of Technology, Isfahan, Iran

ABSTRACT: Artificial vein graft is one of the most commonly used surgeries in the human body, in which the stenosis is replaced with an artificial prosthesis. The mechanical behavior of this prosthesis must be very close to the normal behavior of the vein in order to have an appropriate operation. The carotid artery is one of the major arteries in the blood supply to the human brain. In this paper, the effect of blood fluid on natural and prosthetic vessel walls in normal and occluded cases has been analyzed. Blood flow as a non-Newtonian fluid in the carotid artery has been simulated using ANSYS CFX software. According to the obtained results, the stenosis increases the velocity, shear stress, von Mises stress, deformation as well as local pressure reduction in the occlusion zone. Maximum value of deformation and von Mises stress occurs near bifurcation in the common carotid artery. Then Dacron and polyurethane polymers have been used as replacements for natural carotid artery and von Mises stress and deformation values have been calculated for these polymers in the normal and occluded cases. According to the obtained results, usage of Dacron polymer as a replacement for the natural carotid artery is more appropriate than polyurethane.

Review History:

Received: Dec. 10, 2019-12-10
Revised: Feb.13, 2020
Accepted: Mar. 03, 2020
Available Online: Mar. 13, 2020

Keywords:

Blood flow
Non-Newtonian fluid
Carotid artery
Artificial graft
Computational fluid dynamics

1. Introduction

The carotid artery is one of the main arteries in the blood supply to the human brain. According to the researches, risk of stroke due to stenosis of inner branch of the carotid artery is proportional with the magnitude of stenosis. One of the medical surgeries for treatment of arteriosclerosis is replacement of the occluded or narrowed part of the artery. Artificial vein prosthesis replaces the part of vessel that is not able to perform its duties. Computational Fluid Dynamics (CFD) can provide reliable results for simulating blood flow within the carotid artery. Cibis et al. [1] investigated blood flow in the carotid artery by MRI and CFD methods. With the development of computational power in the last decade, researchers have examined the interaction of structure on blood fluid in the healthy and occluded arteries [2-4]. Teng et al. [5] investigated 3D MRI of the human carotid artery by modeling the interaction of fluid and structure in order to identify the critical wall stress of plaque, critical shear stress of flow and their relationship with plaque rupture. Researchers have looked at two characteristics of durability and blood clotting to find ineffective substances that have the least reaction to blood and vascular tissue [6]. Bagheri-Esfeh and Shanehsaz [7] studied effects of different amounts of stenosis in the carotid artery using computational fluid dynamics. According to the results, stenosis increases the blood viscosity. In the present paper, investigation has been completed and effects of stenosis for different materials of artificial carotid artery have been studied. Also, the effect of blood fluid on the elastic wall of the natural and artificial arteries has been investigated. In this paper, polyethylene terephthalate (Dacron) and polyurethane polymers have been used for artificial vessel walls. These materials have been approved by the US Food and Drug Administration for vascular replacement [8, 9]. Literature review shows that no study has been performed to simulate non-Newtonian blood flow through the occluded artificial carotid artery.

In this paper, the blood flow in the occluded artificial carotid artery is simulated and effect of non-Newtonian blood fluid on elastic wall of the artificial artery is investigated. These are the main innovations of the paper compared to the previous studies.

2- Governing Equations

Equations of continuity and momentum governing the fluid environment are written as follows:

$$\frac{\partial \rho_f}{\partial t} + \frac{\partial}{\partial x_i}(\rho_f u_i) = 0 \qquad (1)$$

$$-\nabla P + \nabla.\tau_f = \rho_f\left(\frac{\partial V}{\partial t} + \vec{V}.\nabla\vec{V}\right) \qquad (2)$$

where Pf, ui, P, f, $\vec{V}$ denote to fluid density, velocity components, pressure, fluid stress tensor and velocity vector, respectively. The subscript f refers to the fluid environment. In this paper, the Carreau-Yasuda model has been used to

*Corresponding author's email: h.bagheri@shr.ui.ac.ir

express the relationship between the viscosity and rate of deformation in the blood [10].

$$\mu = \mu_\infty + \frac{\mu_0 - \mu_\infty}{\left[1 + (\lambda\dot{\gamma})^a\right]^{\frac{1-n}{a}}} \tag{3}$$

Also, the vessel wall is considered elastic to analyze effect of fluid on the structure. The governing equation in the solid environment (vessel wall) is the momentum equation, which is written as follows:

$$\nabla \tau_s = \rho_s \ddot{d}_s \tag{4}$$

The subscript s refers to the solid environment.

3- Methodology

Different parts of the carotid artery have been shown in Fig. 1. Common Carotid Artery (CCA) is bifurcated into Internal Carotid Artery (ICA) and External Carotid Artery (ECA).

Simulation of the blood flow has been performed using Ansys CFX software for steady, laminar and isothermal flow at 37˚C. High-resolution scheme with auto timescale has been used. Blood pressure is 120 mmHg in systolic and 80 mmHg in diastolic. In this paper, the relative pressure of the vessel at the outlet boundary is considered 100 mmHg according to maximum and minimum values of the blood pressure. The speed at the inlet of the vessel varies as a function of time. The input velocity changes sinusoidal so that its maximum value is 0.5 m/s and its minimum velocity is 0.1 m/s during the systolic phase. In the steady-state, the input velocity is considered constant with an average value of 0.3 m/s. Simulation in the fluid domain is performed using computational fluid dynamics and in the solid environment based on a fluid-solid interaction, and the results are finally coupled.

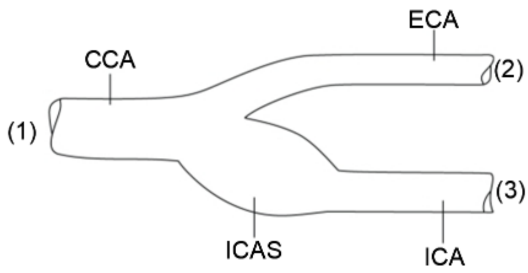

Fig. 1. Different parts of the carotid artery

4- Results and Discussion

Fig. 2 shows average values of velocity, shear strain rate and wall shear stress at different sections of ICA for healthy and occluded carotid arteries. With regard to this figure, for the healthy artery, wall shear stress increases along the ICA. However, this trend has changed for the occluded artery where

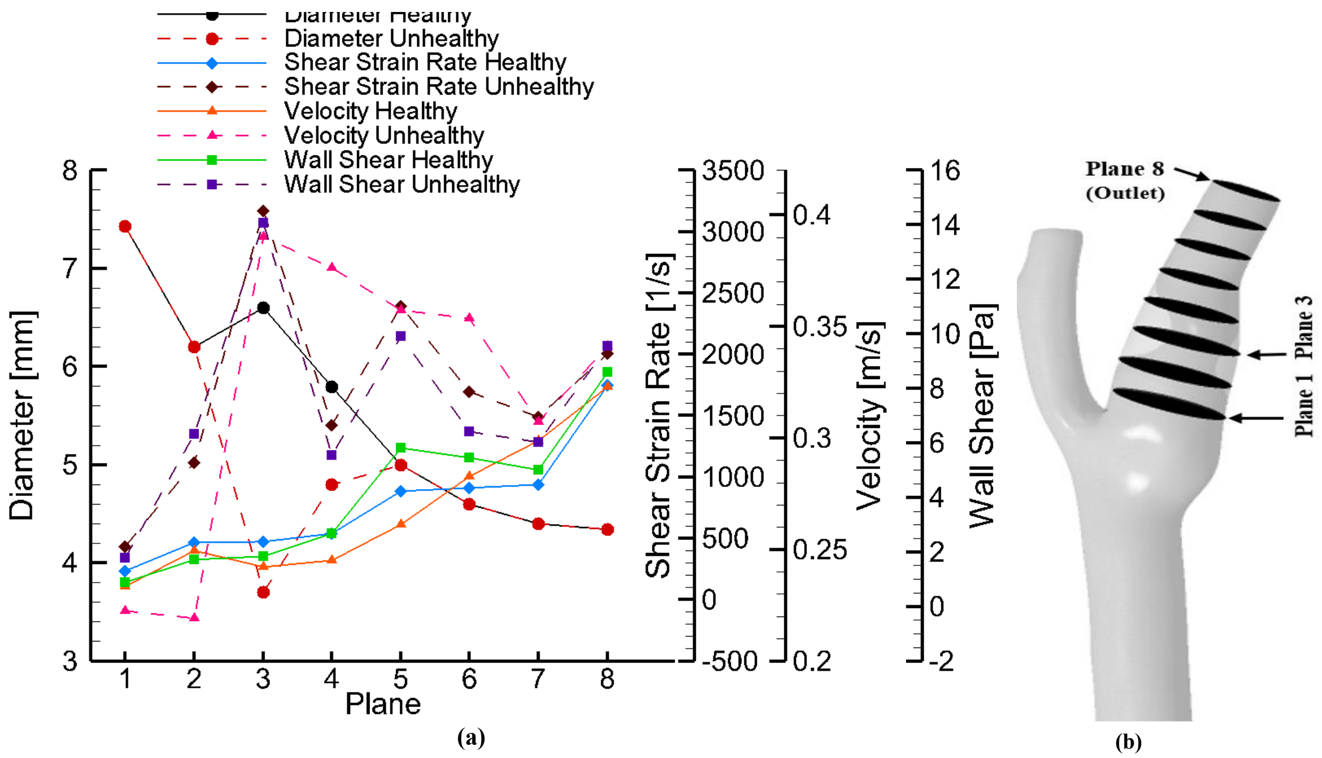

Fig. 2. (a) Average values of velocity, shear strain rate and wall shear stress at different sections of ICA for healthy and occluded carotid arteries, (b) Different sections of ICA

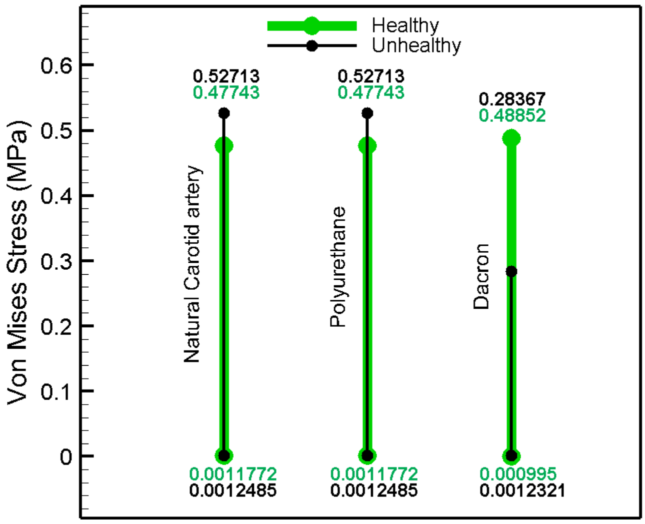

Fig. 3. Range of Von Mises stress for natural carotid artery and carotid artery made of Dacron and polyurethane polymers at healthy and occluded states

the maximum value of shear stress exists at plane 3. Also, stenosis increases the value of wall shear stress. For example, the average value of wall shear stress at plane 3 is equal to 2.5 Pa and 13.5 Pa for the healthy and occluded carotids, respectively. As a result, stenosis delays the separation of blood flow from the artery and making it difficult for blood to return to the heart. Another important result from Fig. 2 is that stenosis increases the shear strain rate in the artery.

ises stress for the natural carotid artery, Dacron and polyurethane at healthy and occluded states. With regard to this figure, stenosis increases maximum von Mises stress for natural carotid and polyurethane, whereas in Dacron maximum von Mises stress decreases for the occluded artery. Table 1 presents the average value of deformation for different materials of carotid artery at healthy and occluded states. With regard to this table, maximum value of deformation is related to the natural carotid and then Dacron and finally polyurethane. Also, stenosis increases the value of deformation up to 5% for different materials. Young's modulus (E) of polyurethane is much more than Dacron. Thus deformation of polyurethane is lower than Dacron.

5- Conclusions

In this paper, blood flow was simulated as a non-Newtonian fluid in the geometry of the carotid artery. Effect of stenosis in the natural carotid artery, Dacron and polyurethane was studied considering fluid-solid interaction. According to the results, stenosis increases velocity, shear stress, von Mises stress and deformation in the carotid artery and causes an interruption in blood return to the heart. Thus the risk of stroke increases. There are many factors that should be considered when choosing an appropriate alternative for the natural artery. Body compatibility, adequate strength, and good elasticity are the most important features of an alternative to the natural carotid artery. In this paper, Dacron and polyurethane polymers were analyzed for alternative of the carotid artery. Structurally, both of Dacron and polyurethane are compatible, non-toxic and approved by the US Food and Drug Administration. Dacron density and Young's modulus are closer to the natural vessel. As a result, its deformation and elasticity are closer to the vessel and greater than polyurethane. Therefore, the Dacron polymer is more suitable than polyurethane to replace the natural carotid artery.

Table 1. Average value of deformation for healthy and occluded carotid arteries and different materials

Material	Deformation (mm)	
	Healthy artery	Occluded artery
Natural carotid artery	3.404	3.585
Polyurethane	0.124	0.130
Dacron	1.727	1.813

References

[1] M. Cibis, W.V. Potters, M. Selwaness, F.J. Gijsen, O.H. Franco, A.M.A. Lorza, M. de Bruijne, A. Hofman, A. van der Lugt, A.J. Nederveen, Relation between wall shear stress and carotid artery wall thickening MRI versus CFD, Journal of biomechanics, 49(5) (2016) 735-741.

[2] S.A. Khader, A. Ayachit, R. Pai, K. Ahmed, V. Rao, S.G. Kamath, Haemodynamics study in subject specific carotid bifurcation using FSI, International Journal of Mechanical and Mechatronics Engineering, 8(11) (2014) 1885-1890.

[3] S.H. Lee, S. Kang, N. Hur, S.K. Jeong, A fluid-structure interaction analysis on hemodynamics in carotid artery based on patient-specific clinical data, Journal of mechanical science and technology, 26(12) (2012) 3821-3831.

[4] A.A. Nejad, Z. Talebi, D. Cheraghali, A. Shahbani-Zahiri, M. Norouzi, Pulsatile flow of non-Newtonian blood fluid inside stenosed arteries: Investigating the effects of viscoelastic and elastic walls, arteriosclerosis, and polycythemia diseases, Computer methods and programs in biomedicine, 154 (2018) 109-122.

[5] Z. Teng, G. Canton, C. Yuan, M. Ferguson, C. Yang, X. Huang, J. Zheng, P.K. Woodard, D. Tang, 3D critical plaque wall stress is a better predictor of carotid plaque rupture sites than flow shear stress: an in vivo MRI-based 3D FSI study, Journal of biomechanical engineering, 132(3) (2010) 1-9.

[6] L. Xue, H.P. Greisler, Biomaterials in the development and future of vascular grafts, Journal of vascular surgery, 37(2) (2003) 472-480.

[7] H. Bagheri-Esfeh, S. Shanehsaz, Study of carotid artery stenosis using CFD, in: 27th Annual International Conference on Mechanical Engineering ISME, Tarbiat Modares University, Tehran, Iran, 2019, (in Persian).

[8] F. Ajalloueian, M.L. Lim, G. Lemon, J.C. Haag, Y. Gustafsson, S. Sjöqvist, A. Beltrán-Rodríguez, C. Del Gaudio, S. Baiguera, A. Bianco, P. Jungebluth, P. Macchiarini, Biomechanical and biocompatibility characteristics of electrospun polymeric tracheal

scaffolds, Biomaterials, 35(20) (2014) 5307-5315.

[9] S. Drilling, J. Gaumer, J. Lannutti, Fabrication of burst pressure competent vascular grafts via electrospinning: effects of microstructure, Journal of Biomedical Materials Research Part A, 88(4) (2009) 923-934.

[10] M. Jahangiri, M. Saghafian, M. Sadeghi, Effects of non-Newtonian behavior of blood on wall shear stress in an elastic vessel with simple and consecutive stenosis, Biomedical and Pharmacology Journal, 8(1) (2015) 123-131.

HOW TO CITE THIS ARTICLE

H. Bagheri-Esfeh, S. Shanehsaz, Comparison of Natural and Synthetic Carotid Arteries in the Normal and Occluded Cases Considering the Effect of Blood on Elastic Wall of Artery, Amirkabir J. Mech. Eng., 53(5) (2021) 665-668.

DOI: 10.22060/mej.2020.17508.6605