26th International Conference
ENGINEERING MECHANICS 2020
Brno, Czech Republic, November 24 – 25, 2020

EFFECT OF RADIUS CHANGES OF MIDDLE CEREBRAL ARTERY (MCA) ON HEMODYNAMIC PARAMETERS

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Abstract: *The article describes the study of the influence of the change in the morphometric features of the middle cerebral artery, i.e. inlet and outlet branch diameters on the values of hemodynamic parameters occurring on the arterial wall – wall shear stress (WSS) and pressure. For numerical calculations ANSYS CFX software was used. A parametric model of the vessel was developed, based on actual anthropometric MCA measurements of patients. Three optimizations were performed by changing individual radius of the arterial branches. The aim of the study was to verify Murray's law for the lowest stress and pressure values. The optimal bifurcation angle calculated in the previous simulations was used.*

Keywords: Hemodynamic parameters, Computational Fluid Dynamics (CFD), Blood flow, Middle cerebral artery (MCA).

1. Introduction

Along with medicine development life expectancy increases. Unfortunately, at the same time frequency of cardiovascular diseases also increases. Said diseases are one of the most frequent reasons for premature death in less developed and developing countries (Nichols et al., 2012). Often the reason for that are pathological changes, resulting with increase of blood vessels diameter. Already existing techniques, such as CT or MRI are being used as standard diagnosing procedures, although they are insufficient in many cases (Williams et al., 2008). This results with necessity of developing hybrid techniques, which combine 3D imagining with advanced numerical CFD models. Numerical simulations and analyses of changes in blood flow resulting from pathological defects can be used for planning the treatment and foreseeing the after-surgery effects. By examining the changes in blood flow resulting from pathological defects and connecting them with biological response, we receive a tool that allows us to estimate development of the disease process, both before and during the treatment. CFD model allows us to commence numerical experiments, which allow designation of significance of interaction between the fluid and structure in blood vessels. For our research an ANSYS software was used for creation of numerical models, which, for simplification, treats blood as one-phase fluid taking into account its non-newtonian characteristic in dynamic condition. Simulations were performed for data taken from measurements commenced on real blood vessels, and the results were analyzed with taking the Murray's law into account.

2. Methods

The sensitivity analysis was performed on parametric arterial models created in ANSYS environment. Arterial morphometric parameters were obtained using CT examination of patients and vascular segmentation in Mimics environment of Materialise. The mean values, minimum and maximum radius

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of each of the branches were calculated from our database. The optimal bifurcation angle calculated in the previous simulations was used (Sobkowiak et al., 2018; Wolański et al., 2018). The aim of the simulation was to verify the operation of the Murray's law, which tells about maintaining the lowest possible energy during flow. This law refers to both the division of angles and the radiuses of individual legs. This work focuses on investigating the radius's values, according to the formula from Murray's law:

$$r_0^n = r_1^n + r_2^n \quad (1)$$

The flow is most energy-efficient when the exponent ‘n’ is 3. The ‘n’ factor for the average radius values (r_0 = 1.36 mm, r_1 = 0.91 mm, r_2 = 1.16 mm) is 2.7. Having the arterial morphometric data, the parametric artery model was modelled in ANSYS Design Modeler software (Fig. 1).

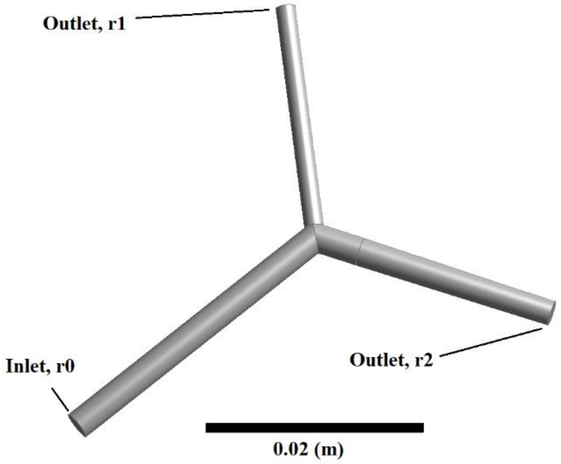

Fig. 1: Designed model in ANSYS Design Modeler software.

The next step was to define the boundary conditions at the inlet and outlet of the artery (Fig. 2), as well as the inflationary layer. The inflationary layer consists of six layers, the first of which is 0.0075 mm high. The next step was to give the material properties of the liquid to be simulated, i.e. blood. The values of blood parameters given in the literature (Fung, 1993; Holzapfel et al., 2010; Lasheras, 2007) were adopted: molar mass - 18.02 kg/kmol, density - 1050 kg/m^3, thermal capacity - 4181.7 J/kg*K, viscosity - 0.0035 Pa*s. The blood was treated as a non-newtonian liquid and the Bird-Carreau model was used in the simulations (Bird et al., 1987). In the simulations the constant blood velocity Vs = 0.45 m/s was used. The model prepared in this way was simulated.

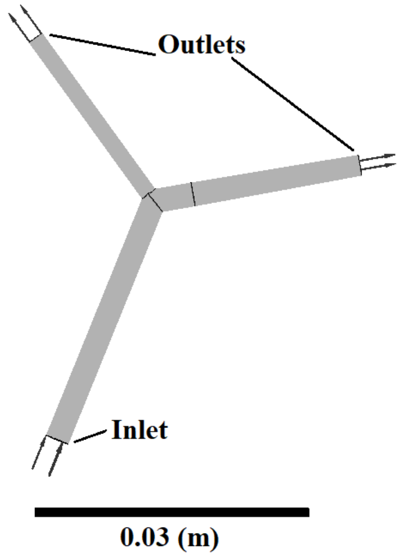

Fig. 2: Boundary conditions.

3. Results

On the basis of the conducted simulations, the results obtained for the change in the values of radiuses r_0 - inlet branch, r_1 and r_2 - outlet branches were compared. The results of the simulation were limited to the bifurcation area in order to avoid errors appearing at the artery inlet. The example of the results of simulation is presented in diagram below (Fig. 3).

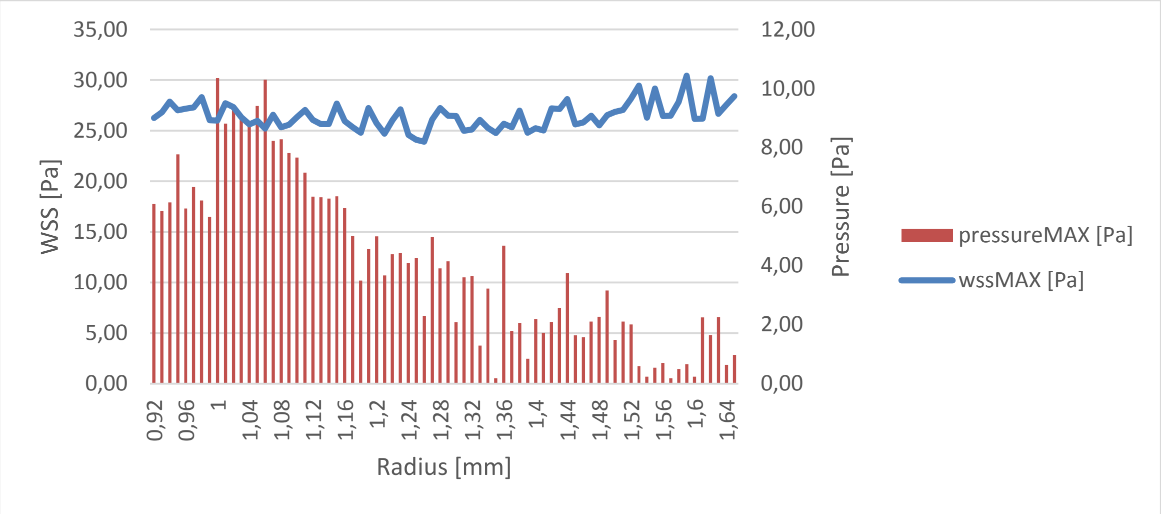

Fig. 3: Influence of a change in the arterial radius value on haemodynamic parameters: wall shear stress and pressure.

The tables below show the values of individual radiuses for ideal conditions at n = 3, minimum WSS and pressure (Tabs. 1 - 3).

Tab. 1: Results of radius r_0.

	r_0 [mm]	n	WSS [Pa]	Pressure [Pa]
Ideal conditions	1.32	3	25.12	3.64
min. Pressure	1.57	1.7	26.47	0.18
min. WSS	1.26	3.9	23.91	2.3

Tab. 2: Results of radius r_1.

	r_1 [mm]	N	WSS [Pa]	Pressure [Pa]
Ideal conditions	0.98	3	24.51	1.77
	0.99	3	27.1	2.45
min. Pressure	0.64	1.8	22.5	3.5
min. WSS	0.76	2.1	25.3	0.25

Tab. 3: Results of radius r_2.

	r_2 [mm]	N	WSS [Pa]	Pressure [Pa]
Ideal conditions	1.21	3	25	0.76
min. Pressure	1.12	2.4	27	0.05

The minimum WSS value for the radius r_2 appears for a radius greater than r_0, hence the determination of the factor 'n' was not possible. From these results it can be concluded that the flow is not the most efficient for minimum WSS or pressure values. The graphics below show an example of a simulation result for the ideal conditions n = 3 (Fig. 4). Maximum values of WSS and pressure occur in the bifurcation region, more on a wider branch.

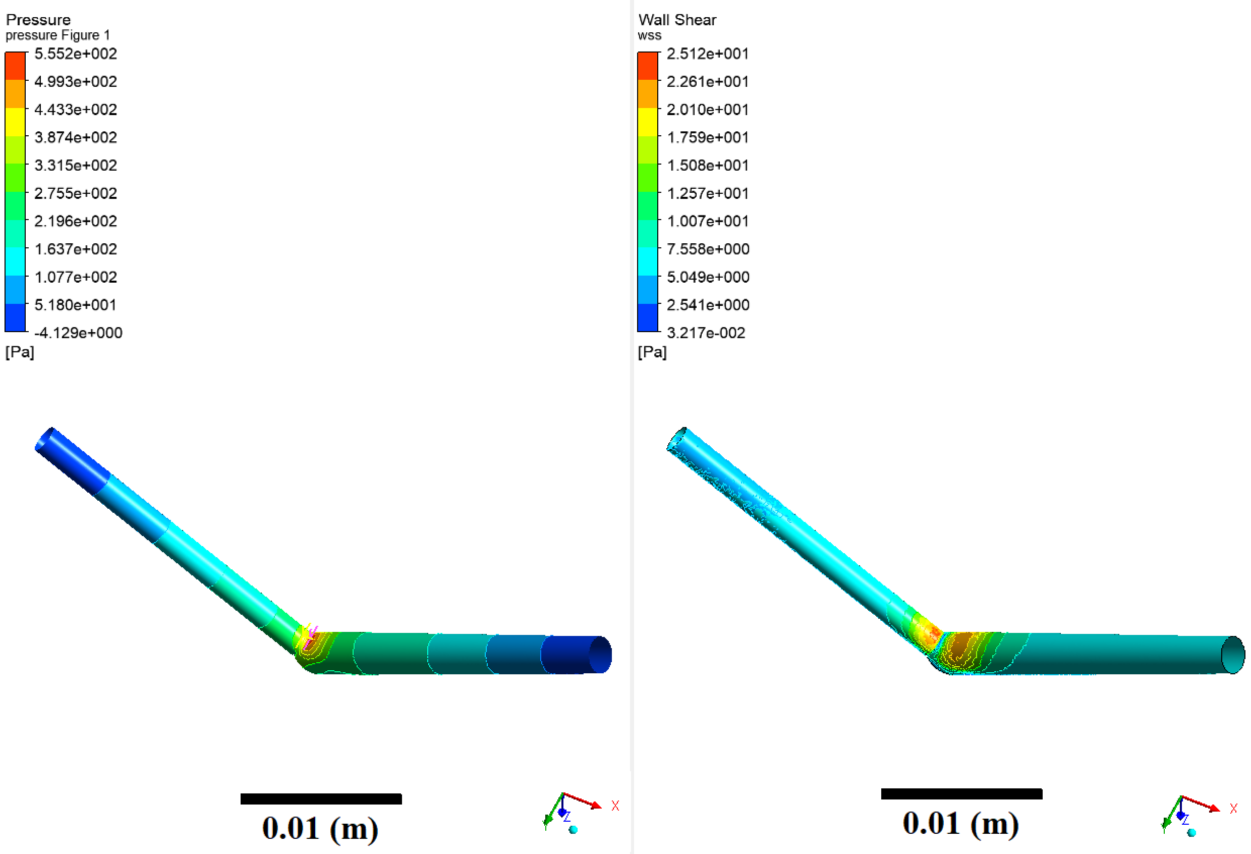

Fig. 4: Results of simulation in Ansys environment – pressure on the left and wall shear stress on the right.

The blood flowing through the vessel affected its wall causing WSS and pressure. Both of these hemodynamic parameters are very important in flow studies.

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