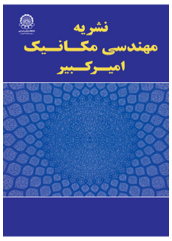

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Comparison of the Hemodynamic Parameters of Sequential Parallel and Cross Configurations of Coronary Artery in the Rest State

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ABSTRACT: Numerical simulation of blood flow in Configurations is the aim of this study. In order to predict the best configuration in a patient with double stenosis 65 and 50 percent is examined at rest. The computational domain was created from CT. In this study, blood is assumed homogeneous, non-Newtonian and pulsatile. To consider non-Newtonian effects the Carreau model is used and, a Seven–element lumped model is used in outlet coronary artery and a Three-element Windkessel model is used in outlet aorta. Results of the Comparison between configurations indicate that is TAWSS minimum is less than the critical value 0.4 in the junction in parallel with the host vessel, In bed and the surrounding junction, furthermore OSI maximum is more than critical value 0.1, Because of sharp curvature of graft branch on the vascular graft. The parallel sequential is more prone than cross with respect to fat accumulation and diseases such as intima hyperplasia. The results of this study indicate by doing bypass surgery, sequential parallel and cross can be improve critical values of shear stress in the area of stenosis and it reduced the risk of rupture of plaque fat and moves the heap toward downstream vessels.

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1- Introduction

Aggregation of lipid deposits leads to arteries stenosis and disturbance of flow in blood arteries. This situation called atherosclerosis, which causes many diseases in circulation system. Appearance of this disease is very common in coronary arteries. If this situation occurs in the heart arteries leads to heart artery occlusion and stroke. Currently, stent placement and Coronary Artery Bypass Graft (CABG) are effective methods to treat disease of Atherosclerosis [1]. Numerical studies of blood flow can have a fundamental role in diagnosis and treatment of arteries occlusion disease. Non-uniform blood flow and stresses imposed on cells and blood plaques can complicate the situation of the disease. The sudden reduction of cross-section of artery causes variations in the hemodynamic forces exerted on the vascular wall and blood plaques. Therefore, more studies are required to be conducted on the behavior of blood flow hemodynamic until reduces the risk of surgery [2]. Due to existence of difficultly and limitation in determination of the hemodynamic parameters for in-vivo and vitro experiments, Computational Fluid Dynamics (CFD) simulations has been selected as the best method to study this problem. Over the last decades, numerous (CFD) studies have been conducted on the blood flow [3].

In this paper, previous studies have been extended on two aspects. Firstly, Seven-Element Lumped model and Three-Element Windkessel model were used in the coronary and aorta outlets, respectively, such as studies of Jonasova [4] et al and Kim et al [5], until the waves of flow and pressure are consistent with the actual physics at rest and exercise conditions. Secondly, time average hemodynamic parameters, such as Time Average Wall Shear Stress (TAWSS), Oscillating Shear Index (OSI), Relative Residence Time (RRT), have been investigated at rest and hyperemia states in order to determine required treatment. In this work, computational geometry is constructed based on (CTA) images. The simulation includes the aorta, left and right coronary arteries and assumes pulsatile flow and pressure condition.

2- Construction of Geometry

Patient-specific volumetric image data was obtained to construct computational geometry for the numerical simulation of blood flow. Cross-sections and central lines of curvature of the coronary arteries derived from (CTA) images with Simvascular software. Then the cross-sections and central lines were transferred to SolidWorks software and the vascular cross-sections connected together. This geometry includes Aorta, Left Circumflex (LCX), Left Anterior Descending (LAD), Right Coronary Artery (RCA), Diagonal 1 (D1) and Diagonal 2 (D2). Triangular computational meshes were constructed in ANSYS ICEM CFD 16.0 (ANSYS Workbench).

3- Governing Equations

In this study, numerical simulation was conducted under unsteady condition. The artery walls were defined as rigid and no-slip. Blood was assumed as incompressible, laminar, non-Newtonian fluid. The motion of blood flow is governed by the continuity Eq. (1) and the momentum Eq. (2) [6].

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$$u_{i,j} = 0 \tag{1}$$

$$\rho\left(\frac{\partial u_i}{\partial t} + u_j u_{i,j}\right) = -p_i + \tau_{ij,j} \tag{2}$$

where u is blood velocity, ρ is blood density and τ is the stress tensor which is defined by Eq. (3)

$$\tau_{ij} = \mu_{\text{eff}} \dot{\gamma}_{ij} \tag{3}$$

where μ_{eff} and $\dot{\gamma}$ denote the viscosity of blood and shear rate, respectively. In this work, the relation between μ_{eff} and $\dot{\gamma}$ are described by Eq. (4)

$$\mu_{\text{eff}} = \mu_{\text{eff}} + \left(\mu_0 - \mu_\infty\right)\left[1 + \left(\lambda\dot{\gamma}\right)^2\right]^{\frac{(n-1)}{2}} \tag{4}$$

where μ_0=0.056 Pa.s, μ_∞=0.056 Pa.s, λ=3.313 s and n=0.3568 and the shear rate $\dot{\gamma}$ is defined by Eq. (5)

$$\dot{\gamma} = \sqrt{2tr[\frac{1}{2}\left(\nabla u + \left(\nabla u\right)^T\right]^2} \tag{5}$$

4- Computational

The submitted papers to the journal should be in both to ensure periodic nature of the flow the simulations were performed for three cardiac cycles (pressure pulse) where each cycle is 1 s and 0.5 s at rest and exercise conditions, respectively. The results from three cardiac cycles are discussed in the results section. The numerical calculations were carried out using Finite Volume Method (FVM) in ANSYS FLUENT software. Temporal discretization was performed with a second order backward Euler scheme and the spatial discretization used second order central differencing. Pressure was solved through the pressure-velocity coupling method known as the SIMPLE algorithm. The residual for solution was kept at 0.00001 and the simulations progressed with a time step of 0.0025 s and 0.001 s at rest and exercise conditions, respectively. The computational mesh utilized in primary simulations consisted of nearly 1,497,801 and 2,485,123 Triangular elements for health and patient geometry, respectively. The transient simulations were performed with personal computer with 3.6 GHz Core *i*7 Duo processor with 16 GB of RAM.

5- Results and Discussion

Fig. 1 is showing geometry that included branches of LAD, D1 and D2 at healthy state. In this research, Stenosis with degrees of 30%, 65% and 80% applied to normal geometry in LAD branch, in order to validation of results of flow and pressure waves. Fig. 1 showing the relationship between a mean coronary flow and degree of stenosis is comparable to the plots obtained from experimental techniques at rest and exercise conditions. Gould et al created temporary stenosis in the left circumflex artery of canines and injected blood to simulate hyperemic conditions (exercise conditions) in canine coronary arteries. They observed that the mean flow did not decrease up to 85% diameter reduction at rest state and 30–45% diameter reduction at hyperemia state. In this research, the branch of LAD has been affected by stenosis 30, 65 and 80 percent. Fig. 1 shows the mean flow in the stenosis artery in both resting and exercise conditions. We also plotted the experimental results of Gould et al. for comparison. Fig.1 showing mean flow is place in the range of experimental data in both resting and exercise conditions [7,8].

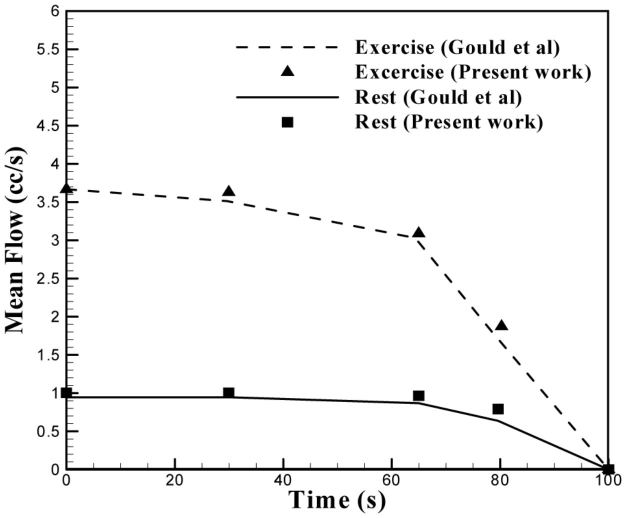

Fig. 1 Compare the mean flow time in normal, 30, 65 and 85 stenosis with experimental results artery in the state of rest and exercise [7]

6- Conclusions

In this study, the geometry of patient compared with geometry of healthy with method of 0D/3D at rest and exercise conditions. Waves of pressure and flow modeled in outlets of aorta and coronary realistically, using lumped parameter models. The results indicated drop of pressure and flow at exercise are more than rest, because more energy loss occur as more flow travels through the coronary arteries. This concept is verifiable by expressing two cases. The first case is results of Gould et al that indicated the mean flow did not decrease up to 85% diameter reduction at rest and 30–45% diameter reduction at exercise. The results of this study indicate by doing bypass surgery, sequential parallel and cross can be improve critical values of shear stress in the area of stenosis and it reduced the risk of rupture of plaque fat and move the heap toward downstream vessels.

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