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Numerical Simulation of Blood Flow through a Segment of an Artery with Single Stenosis

F. SHAIKH, M.S. CHANDIO*, Z. KALHORO*

Department of BS &RS, Mehran UET, Jamshoro,

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Abstract: In this paper, incompressible and isothermal blood flow through segment of large artery with single symmetric stenosis is investigated. For Numerical simulation Finite Element Semi Implicit Time-stepping Taylor/ Gale kin Pressure Correction Scheme is employed to seize steadiness and reliability of the numerical scheme at stenosis that grounds laminar flow region to turbulent. Results of simulation are carried out on different Reynolds number 10, 400 and 1000.Velocity, pressure and streamlines are the important parameters for the analysis which are obtained for various stenos is ratios i-e 30% and 50%. Behaviour of blood is highlighted through different apparent parameters at stenosis and near the stenos is on different Reynolds numbers. Further, it has been critically noted that, high disturbance of blood flow occurs at the 50% stenos is size with Renolyd number 1000.

Keywords: Incompressible, Isothermal, Laminar, Stenosis, Finite Element

1. INTRODUCTION

Today's increasing disease especially in developing countries is cardiovascular disease especially, atherosclerosis, that causes deaths. Plaque that builds up in the artery by combining the cholesterol with fat, calcium and other substances in the blood and artery become narrow and resist the flow of the blood. This can lead to heart attack, strokes and other cardiovascular diseases. The mathematical study of blood flow through artery is noteworthy to many medical problems especially when some sort of stenosis develops as a resistance during flow which creates the health problems for human body. For studying such fluid flow, several methods such as experimental, mathematical analysis and numerical simulation are employed.

Recent research reviews have been studied to identify the structure of the artery with the stenosis. Investigation on non-Newtonian arterial blood flow model with multiple stenoses has been done by Kumar *et al.,* (2014) and concluded that with the accession of red blood cell and viscosity of the blood reduces the wall shear stress. Mir *et al.,* (2014) has examined Incompressible two dimensional flow simulation for Reynolds's number 300. Maximum shear stress values were observed in the wall confiscated near the throat while moderately low in the end of the stenotic region with high flow disturbance (Rabby *et al.,* 2014). Jun-Mei Zhang *et al.,* (2014) divulged the effect of stenosis diameter from 45% to 75% and length from 4 to 16 mm and 4 different positions on fractional flow reserve.

Shaikh has investigated blood flow in the branched artery with the blockage of 20, 50, and 80% and resulted that in 80% blockage shear rate is high in the recirculation area additionally shear rate increases with increasing Reynolds number. Benchawan *et al.,* (2012) assumed pulsatile flow in coronary artery by using Bubnov-Galerkin finite element method and resulted that pressure reduces along the branches of the arteries and wall shear stress increase. Study is done on the reattachment region by calculating velocities of laminar flow (Shaikh, and Chandio, 2014).They resulted that higher the Re number, the flow disturbs high and lower the Re number, smooth the flow of fluid. Investigation was done on the irregular stenosis of 3D computational model using finite element volume (Agrawal, 2015). Gupta and Garewall concluded that using Re=130-540, wall shear stress is swinging in a complex way that normal stenosis.

Basu *et al*. (2013) investigated the flow at value of slip velocity 0.05 and no slip velocity and resulted that viscosity decreases in the presence of slip and velocity and flow rate increases. Pankaj (2013) simulated bell shaped stenosis using power law. He concluded that the pressure drops and shear stress increases as the size of the stenosis increases for a non-Newtonian model of the blood. Computation of slip velocity in the axisymmetric stenosedartery with the catheter was measured in this research work by (Reddy and Srikanth, 2015). Reddy and Srikanth has used Mathematica and Matlaband resulted that wall shear stress increases or decreases if radius of the catherter, increases/decrease.

++Corresponding author zubairabassi@gmail.com
*IMCS, University of Sindh, Jamshoro

Problem geometry and Boundary conditions

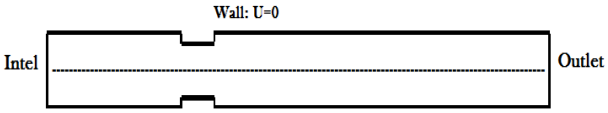


Fig. 1. Geometry of a segment of artery with stenosis

Flow at inlet is completely evolved and zero outlet pressure is considered in this research work. Zero-slip boundary conditions are applied on the walls as follows: $U_x = V_x = 0$

Governing Equations

In this paper, 2D Incompressible, laminar, Newtonian fluid in the artery is considered. Due to variation in the temperature, isothermal flow is considered. Continuity and momentum equations are included as governing equations and described as follows:

$$\rho\left(\frac{\partial u}{\partial t} + u.\nabla u\right) = \nabla.\sigma + \rho F \qquad (1)$$

$$\nabla.V = 0 \qquad (2)$$

where velocity is u and density of the fluid is ρ.For incompressible Newtonian fluids, the stress tensor τ is stated as $\tau = 2\mu D$

Rate of deformation tensor Dandvelocity gradient L, is defined as:

$$D = \frac{(L + L^T)}{2},\ L^T = \nabla u \qquad (3)$$

Describing the non-dimensional variables for velocity, pressure and time u^*, $p^*$and t^* respectively, discarding the '*' notation above equation can be rewritten as (4) and (5).

$$\frac{2\,\mathrm{Re}}{\Delta t}(u^{n+1} - u^n) = [\nabla.(2\mu D) - \mathrm{Re}\,u.\nabla u]^n - \nabla p^{n+1} \qquad (4)$$

$$\nabla.u^{n+1} = 0 \qquad (5)$$

where Re is the non-dimensional number and is defined as:

$$\mathrm{Re} = \frac{\rho V L}{\mu}$$

Numerical Method

In this paper, Finite element method is used and for discretization semi-implicit Taylor-Galerkin/Pressure-correction is used. Velocity and pressure regions are estimated:$u = \sum_i u^i(t)\phi_i(x)\ and\ p = \sum_j p^j(t)\,\Psi_j(x)$

$\phi_i(x)$ is the parabolic (quadratic) shape for the velocity and $\psi_j(x)$ is the linear shape function for pressure. The corresponding semi-implicit Taylor-Galerkin/Pressure-correction form of equations may then be expressed in matrix-form as:

$$M_{ij} = \int_\Omega \phi_i\phi_j d\Omega,\ N(U)_{ij} = \int \phi_i\phi_j U\ \nabla\phi_j d\Omega$$

$$((L_k)_{ij}) = \int_\Omega \Psi_i \frac{\partial \phi_j}{\partial x_k} d\Omega,\ K_{ij} = \int_\Omega \nabla\Psi_i \nabla\Psi_j d\Omega$$

$$Si_j = \int_\Omega \nabla\phi_i \nabla\phi_j d\Omega$$

where M, S, N(U), L, K, are consistent mass-matrix, diffusive matrix, convection matrix, pressure-gradient matrix, pressure-stiffness matrix, respectively.The matrix equation then be solved by Choleski's method.

2. RESULTS AND DISCUSSIONS

In the present study, the simulation is presenting the results of various velocity profiles, contour plots of streamline functions, pressure profiles of 30% and 50% blockage with different Reynolds number in the segment of an artery with single symmetric stenoses. An important factor in this simulation is Reynolds number that describes the value of flow rate at different regions of the artery. In this research paper meshes of single symmetric of 30% and 50% blockages are generated using IDEAS software in order to capture the solution accurately.

Velocity contours, pressure contours and streamline are the main parameters of this study. For blockage 30%and 50%, parabolic velocity profile is observed at inlet as well as at outlet of single symmetric stenosed artery whereas for blockage 50%, more force is required to pass the fluid from narrow region see **(Fig. 2 a, b).** Velocity contours of both 30% and 50% blockages with different Reynolds number are shown in the figure 3 and4 respectively. For blockage 30%, fluid is speedy at inlet also at stenos is site as the Reynolds number increases see **(Fig. 3)**whereas maximum velocity is observed at stenosis site with more force due to narrow region for 50% blockage. Disturbance is seen at upstream and downstream end of the stenosis that causes the reversal flow and increase the size of the stenosis see **(Fig. 4).**Further, it is clear from the figure 5 and 6 that maximum pressure is seen at inlet for low Reynolds number and increases and reaches near stenosis as the Reynolds number increases see **(Fig. 5,6,7).** From higher recirculation region at exit up and down of the stenosis is seen with higher Reynolds number whereas from **(Fig.8)**, at low Reynolds number small flow reversal is seen that decelerates the flow and vortex develops with high intensity as Reynolds number increases and the turbulence properties of flow appears.

This reversal phenomenon increases the possibility of thrombosis or increases the size of stenosis and cause severe disease.

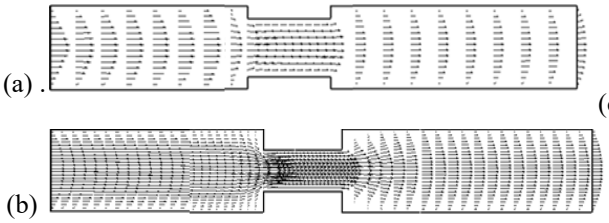


Fig. 2: Velocity vector for blockage 30% (a) and 50% (b)

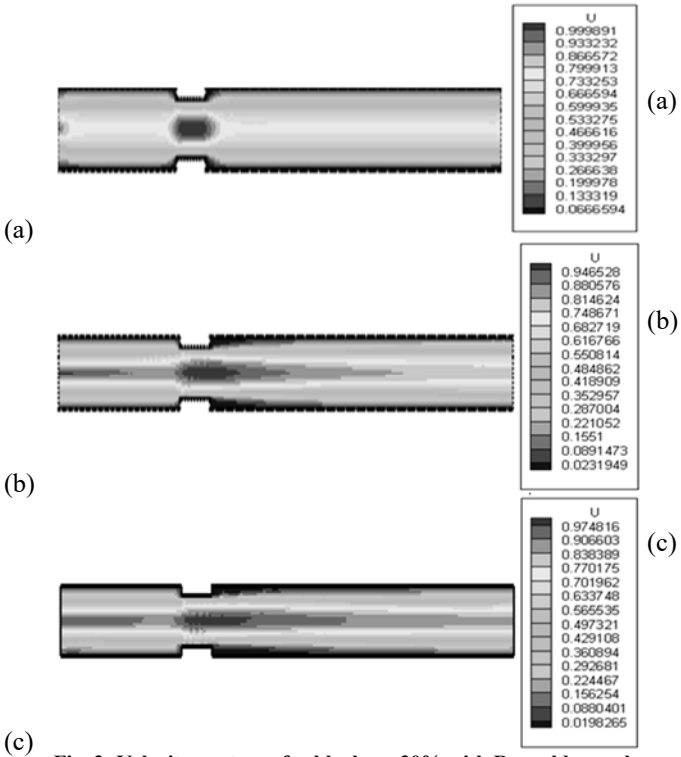


Fig. 3: Velocity contours for blockage 30% with Reynolds number (a) 10 (b) 400 (c) 1000

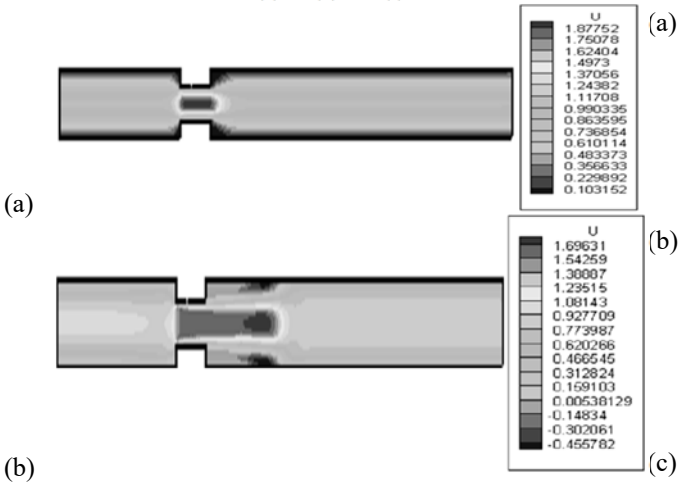




Fig. 4: Velocity contours for blockage 50% with Reynolds number (a) 10 (b) 400 (c) 1000

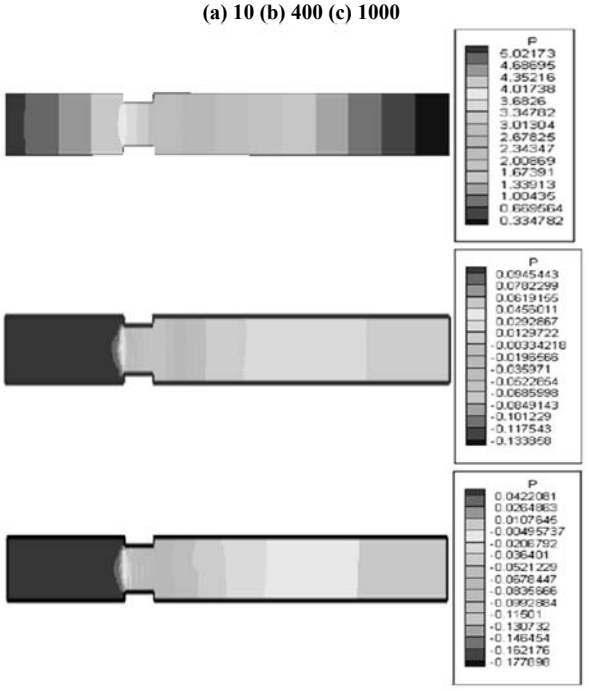


Fig. 5: Pressure contours for blockage 30% with Reynolds number (a) 10 (b) 400 (c) 1000

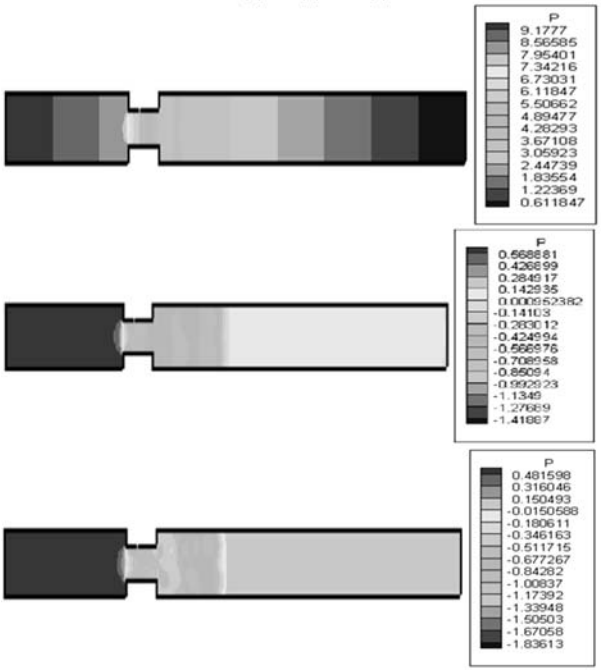


Fig. 6: Pressure contours for blockage 50% with Reynolds number (a) 10 (b) 400 (c) 1000

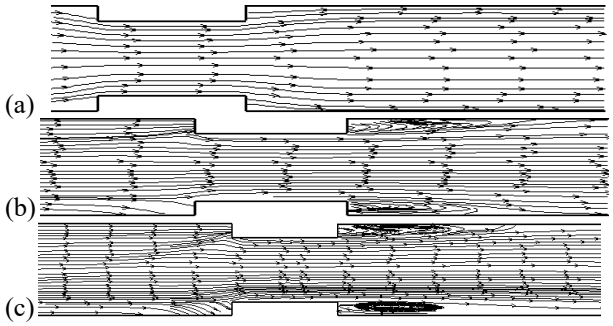


Fig. 7: Streamline function for blockage 30% with Reynolds number (a) 10 (b) 400 (c) 1000

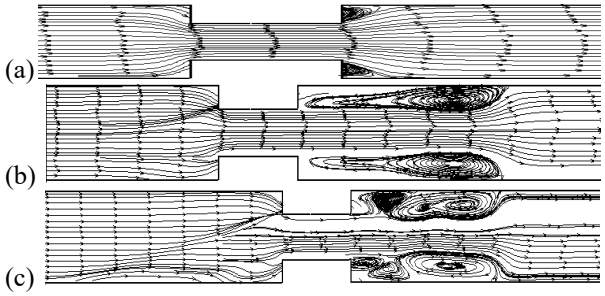


Fig. 8: Streamline function for blockage 50% with Reynolds number (a) 10 (b) 400 (c) 1000

3. CONCLUSION

It has been observed that, when the stenosis increases from 30% to 50%, the change in flow patterns is more complicated. The presence of a severe stenosis generated two different flow regions in the artery. One is the initial region of stenosis in the artery and exhibits high velocity and pressure. The second is located immediately up and downstream of the stenosis, where flow set back with low velocity and pressure.

Moreover, in this paper, we observed that at blockage 30% as well as 50% with increasing Reynolds numbers, velocity and pressure decreases due to viscous effect at the site of stenosis and separation occurred higher near the up and downstream end of the stenosis. While the reattachment point relocated at greater distance. The length of the vortex elongated with increasing R*e* number. At blockage 50%, we have also observed the flow reversal upstream and downstream of the stenosis is severe as compare to 30% due to narrow region at stenosis. It can further be observed from the given figures that the presence of flow reversal does not exist at initial stage and weak stenosis is seen. With increasing Reynolds number, it has developed with high intensity. This might convert these vortices into lumps that later causes the development of atherosclerosis or clots and cause severe disease.

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