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Influence of Different Dimension of Stenoses on Non-Newtonian Fluid Blood's Behavior through a Single Stenosed Artery

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ABSTRACT: A numerical simulation of two-dimensional laminar pulsatile flow of Non-Newtonian fluid blood through a stenosed artery has been studied. Here the calculations are carried for five different dimensions of a single stenosed. A rigid wall vessel is considered and for inlet velocity profiles an oscillatory physiological and parabolic velocity profile has been imposed. In these investigation Non-Newtonian formative equations- Carreau model for blood has been calculated and also the result of fluid behavior is compared for five cases. Axial velocity, inlet velocity profile, pressure, wall share stress distribution, pressure loss, cross sectional velocities as well as the streamlines contour has been calculated from the investigation and compared for the different dimension of stenosed. From the result it is shown that the velocity and WSS is higher at stenosed region than after and before stenosed region and pressure is dropped at stenosed region then other region for all phases and increment of stenosed height causes more increment of velocity and WSS compare to increment of length.

KEYWORDS: Laminar pulsatile flow, Non-Newtonian fluid, Carreau mode, streamlines contour, velocity profile Include, wall share stress distribution and pressure loss.

1 INTRODUCTION

At today the simulation of blood flow as a Non-Newtonian fluid is more interesting, demanding for medical science as well as bio-medical sector and important to the researchers. And also this cardiovascular system has been investigated from many years. Basically, the blood is pumped by heart which is covered and attached by a branching tubes network and these tubes suck the blood from heart and the blood vessel supplies blood to different organs with nutrition. Two types of vessel artery and veins are carried blood. Artery mainly carries different blood cell from heart to different part of body and veins carry blood cell from body to heart. The artery of human or animal body is strong and flexible that's why it is common to create reduction of artery's area or narrowing's which is referred as stenoses, caused by intravascular plaques. And the regular blood flow pattern of the artery is disturbed by theses stenoses. And the initial formation of these stenoses is happened due to the deposit of fatty substances like cholesterol and by Mandal and Amin "some researchers opined that the damage to the inner coating of the artery, the intima, is responsible for the initial formation of stenoses [1]." In fact, the vessel wall's mechanical behavior and movement of blood are known as the major causes in the formation of blood vessel stenosis [2]. As stenoses Disturb the blood flow and regional blood rheology so these create coronary artery diseases among them atherosclerosis is one of the most causes of human morbidity and mortality [3]. And so due to these diseases a numerous number of investigation and studies has been conducted and also at present continuing on this issue to locate and find the reasons of starting and developing of atherosclerotic lesions and also determine the influence and important of mechanical factors such as wall shear stresses, pressure and velocity gradients, resistance to blood flow in atherosclerosis pathogens. Because of this different investigation have formed a correlation between pathological and mechanical factors and which initially gave attention on the wall shear stress [4].

Wall shear stress, pulsatile blood flow and pressure gradient through the stenosis with elastic wall to analysis the movement of lumen and causes the rupture plaque are studied and investigated by Young et al. [5]. From their study they find the minimum lumen position just before the peak wall share stress. Wall share stress, flow separation zone and pressure drop etc. hemodynamic characteristic of 55% irregular stenosis are investigated by Zanous Shafaghat1 and Esmaili [6]. By their investigation the maximum wall share stress is related to the minimum cross-section area and maximum gradient of velocity. They also claimed that 55% stenosis irregularity has the potential to damage the cell layer of endothelium with oscillatory distributions of WSS. Another research on axi-symmetric single or repeated stenoses in coronary arteries is carried by Morteza Kimiaghalam and Zavid [7]. They claimed “the vulnerability of atherosclerotic lesions and enhancement of further stenotic sites are far worse than what is anticipated by laminar analysis since WSS varies from zero to 1.3 Pascal during every period which is more than 3 times the variation of the WSS of the laminar flow.” Physiological pulsatile flows through various models of stenosis are studied by Pinto et al. [8]. In another study, for non-Newtonian fluid trapezium, semi-ellipse and triangle geometric stenosis have been studied by Lorenzini and Casalena [11]. The authors investigated that the length of flow disturbance is due to stenotic shape, downstream disturbance is due to stenotic walls and peak velocity depends on the shape of stenosis.

From above discussion it is clear that there are so many research on non-Newtonian blood flow through single stenosed artery but very few research on Newtonian and non-Newtonian blood flow comparision and different dimensional and percentage single stenosed. And so in this study 50%, 66.67% and 80% of radius dimension’s has been considered stenosed for artery and wall share stress, velocity and pressure gradient, resistance to flow and pressure drop has been calculated for all condition.

2 METHODOLOGY

Laminar two dimensional unsteady and fully developed flow of blood is considered through an axially symmetric long elastic tube having a stenosis in its lumen in the present study. Let in the cylindrical polar coordinates system the material point’s coordinates is (r, θ, z) where r and θ are located along the radial direction and z is taken along the axis of the artery. Also consider that the geometry is axisymmetric $\left(\frac{\partial}{\partial\theta} = 0\right)$ and vanished the component of azimuthal velocity for the sake of computational analysis. And under these assumptions the governing momentum and continuity equation for z and r components are described together by the following equation:

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial r} - \frac{1}{\rho}\left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rz}) + \frac{\partial}{\partial z}(\tau_{zz})\right] + G(t),$$

$$\frac{\partial w}{\partial t} + u\frac{\partial w}{\partial r} + w\frac{\partial w}{\partial z} = -\frac{1}{\rho}\frac{\partial p}{\partial r} - \frac{1}{\rho}\left[\frac{1}{r}\frac{\partial}{\partial r}(r\tau_{rr}) + \frac{\partial}{\partial z}(\tau_{rz})\right]$$

$$\frac{\partial w}{\partial t} + \frac{u}{r} + \frac{\partial w}{\partial z} = 0$$

Here the relationship between two-dimensional share rate and share stress are as follows:

$$\tau = -m\left[\left|\sqrt{0.5(\dot{\gamma}.\dot{\gamma})}\right|^{n-1}\right]\dot{\gamma}$$

$$0.5(\dot{\gamma}.\dot{\gamma}) = 2\left\{\left(\frac{\partial u}{\partial r}\right)^2 \left(\frac{u}{r}\right)^2 \left(\frac{\partial w}{\partial z}\right)^2\right\} + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial r}\right)$$

Here, n= fluid behavior index parameter, m= consistency, p= pressure, τ= stress tension; $\dot{\gamma}$= symmetric rate of deformation tension and u(r,z,t) and w(r,z,t) are the radial and axial velocity components. A nondimensional number usually referred to as the Womersley or Witzig [12] is commonly used to analysis the dimension of unsteady Navier-Stokes equation:

Parameter: $\alpha = R\sqrt{\frac{w}{v}}$

Where R is the tube radius, ω is the angular frequency, and ν is the kinematic viscosity (Womersley 1955). The ratios of the unsteady forces to the viscous forces are influenced by this parameter. Velocity profile is parabolic shape and viscous forces dominate when Womersley parameter will be low. And if this parameter is above 10 then the unsteady inertia forces dominate and the motion is introduced with a flat velocity profile.

For Newtonian and non-Newtonian model blood have different equation for viscosity and table 1 represents the equations:

Table 1. Blood Properties

`Model	Effective Viscosity
Carreau →Carreau[13]	$\mu(\lvert\dot{\gamma}\rvert) = \mu_\infty + (\mu_0 - \mu_\infty)[1 + (\gamma\dot{\gamma})^2]^{(n-1)/2}$ $\mu_0 = 0.056\ Pa.s$ $\gamma = 3.313$, time constant; n= 0.3568 $\mu_\infty = 0.00345\ Pa.s$

3 GEOMETRY

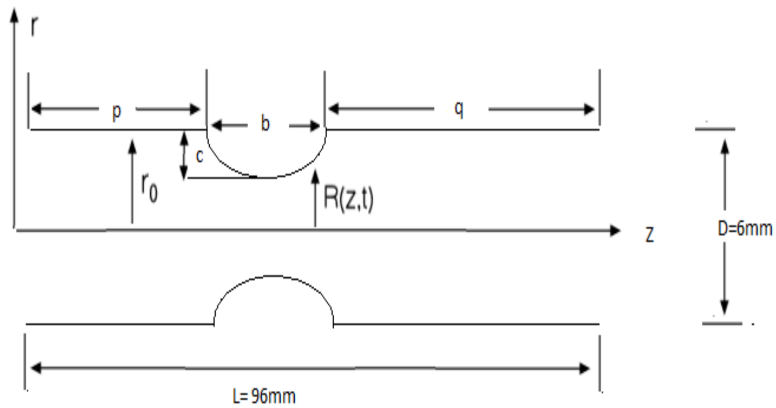

Fig. 1. Schematic Diagram of Stenosed Artery

Here a two dimensional a single half circle stenosed artery is consider as geometry which length L=96mm and D=6mm, p=before stenosed region, q= after stenosed region b= stenosed length, c= stenosed height and for this analysis we consider 5 cases on the basis of stenosed dimension-

Case 1: b=2D, p=4D, q=10D and c =1.5mm or 50% of D

Case 2: b=2D, p=4D, q=10D and c =2mm or 66.67% of D

Case 3: b=2D, p=4D, q=10D and c =2.4mm or 80% of D

Case 4: b=2.5D, p=4.5D, q=9D and c =2mm or 66.67% of D

Case 5: b=1.5D, p=4D, q=10.5D and c =2mm or 66.67% of D

4 BOUNDARY CONDITION

For the unsteady/ pulsatile blood flow, the inlet velocity is assumed to be uniform with a sinusoidal waveform:

Pulsatile flow velocity: $u = U_m(1 + \sin(2\pi t))$

u= velocity of the flow

U_m= mean axial velocity and t= time

At the outlet, 13337 pa gauge pressure is prescribed. For each simulation case, different inlet velocity boundary conditions are imposed. A no-slip boundary condition is imposed at the walls of the arteries.

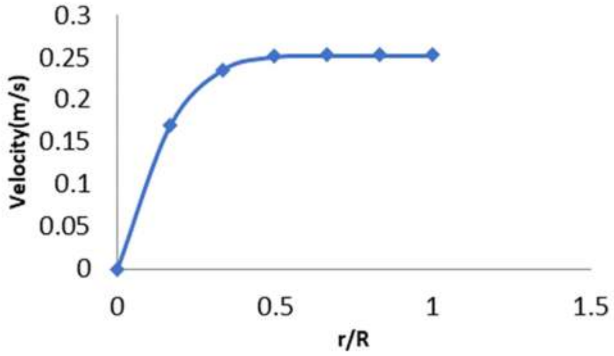

Fig. 2. Inlet velocity profile with respect to radial distance

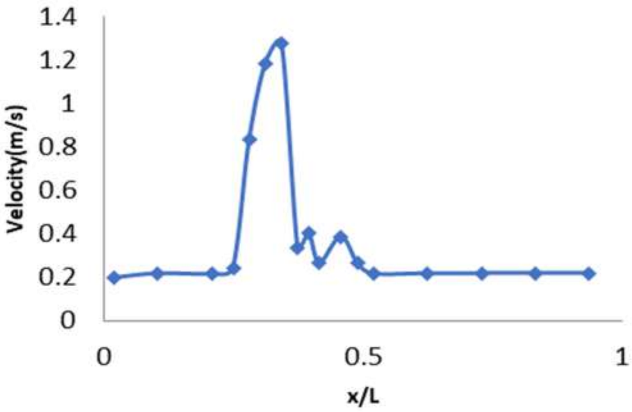

Fig. 3. Pulsatile velocity distribution with respect to axial distance

5 GRID INDEPENDENCE TEST

For different mesh element mesh 1 (4605), mesh 2 (5000) and mesh3 (4450) figure 4 shows the similar value of pressure distribution through the tube and stenosed section that means the solution satisfy the grid independence test.

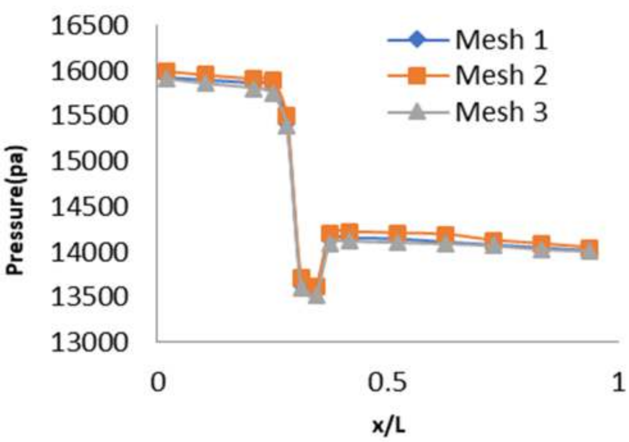

Fig. 4. Variation of pressure distribution for different mesh number

6 Numerical Result And Discussion

For the numerical investigation Ansys Fluent 16 software has been used to flow blood as fluid through the stenosed artery. Here velocity-pressure coupling is adapted by simple algorithm and under the effect of discretization scheme; second order Upwind scheme is employed as a numerical method for the momentum equation is prescribed. The time step is set to 0.1 sec with 2000 maximum 35 iterations are performed per time step. In this study the effect of stenosed on the behavior of flow has been numerically analysis for case 1, case2, case3 and case4 respectively.

6.1 Effect of Pressure on Flow Behaviour

The figure 5, 6 and 7 shows the pressure distribution through the entire tube with different position for case1, case2, case3, case4 and case 5. From the graph it is clear that before throat section the pressure is very high, at throat region the pressure drops rapidly for all the case and after throat section the pressure rise and it remains constant to the outlet. And this similar distribution of pressure is obtained from Ali and Akhter's [12] research work who take 85% stenosed and they observe a very large pressure loss at throat region. In the present study at case3 (80% stenosed) more pressure drop is obtained compare to other and case1(60% stenosed) show low pressure loss and at case 5 (stenosed height 66.67% and length 2D) pressure after throat is increase very low compare to other and at the middle point of throat we get the peak point because here pressure is very low and this pressure drops at throat section is happened because of the reduction of tube area suddenly which increase the velocity and decrease pressure and the more the reduction of area the more the pressure loss. And figure 8 shows the comparison of pressure distribution for case 1, case 2 and case 3 from which the throat pressure of case 3 is very low compare to others.

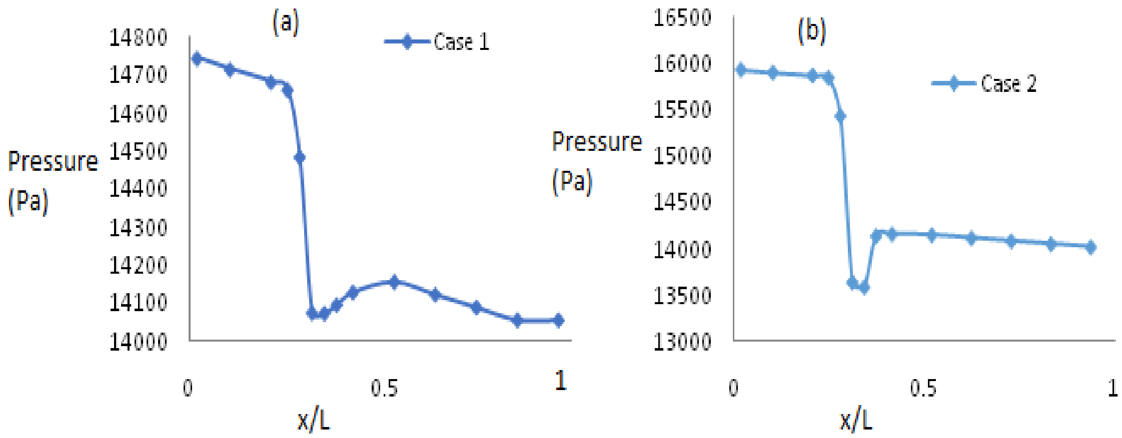

Fig. 5. Effect of Pressure distribution for case1, case2 with respect to x/L

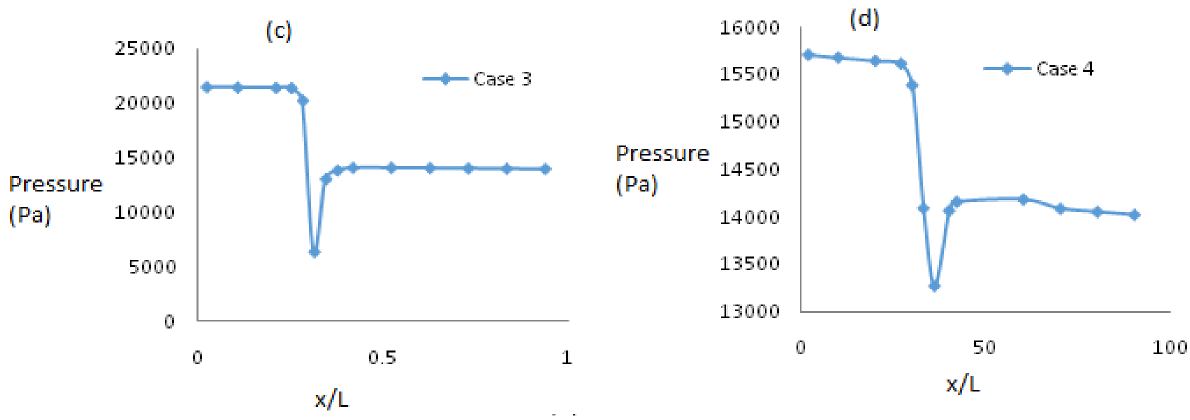

Fig. 6. Effect of Pressure distribution for case3, case4 with respect to x/L

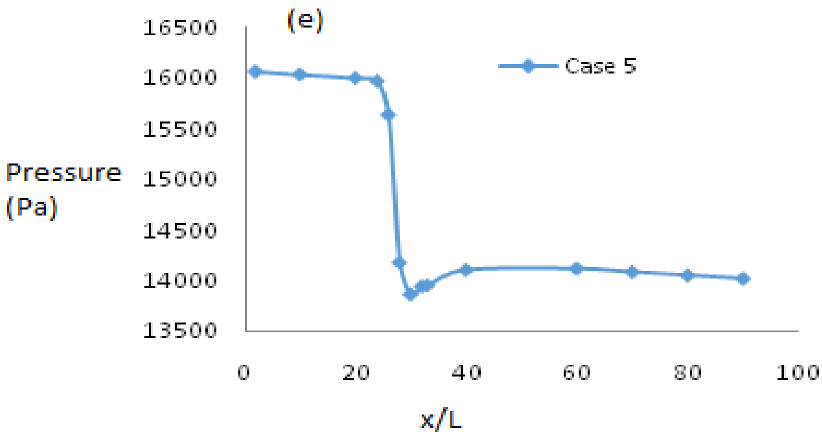

Fig. 7. Effect of Pressure distribution for case5 with respect to x/L

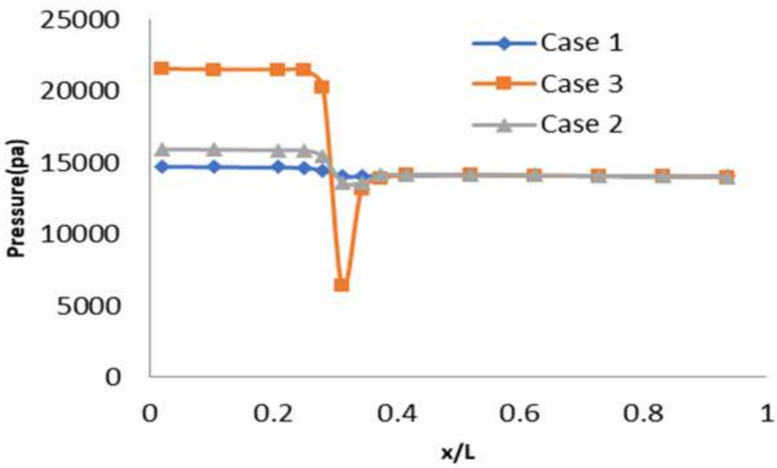

Fig. 8. Variation of Pressure distribution for case1, case2 and case3

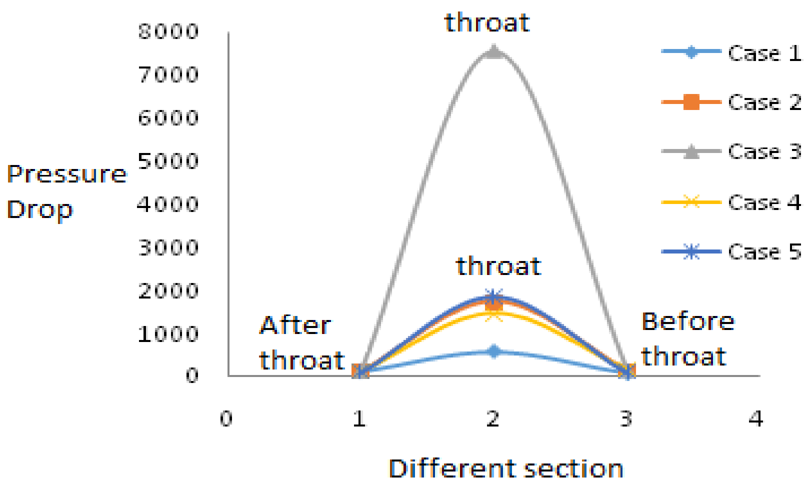

Fig. 9. Comparison of pressure drop for all case at after throat, throat and before throat region

6.2 Variation of Wall Shear Stress (WSS) Distribution With Axial Distance

The figure 10 shows the WSS distribution through the entire artery for all cases. From the all graphs it is clear that at throat region the value of WSS is very high compare to other two regions this is happened because of huge loss of pressure at this section. The graphs also reveal that for case 3 the WSS is more at throat region and for case 1 the WSS is less compared to others. That means if the artery's area at throat section has been reduced or throat height is increased then the WSS is increased and on the other hand if throat length has been reduced then the WSS is increased that can be observed from case 4 and case 5 and this increment is less than previous condition. And the figure 11 shows the variation of WSS for case 1, 2 and 3 where case 3 gives more increment of WSS. And figure 12 indicates the variation of WSS for different case at throat region.

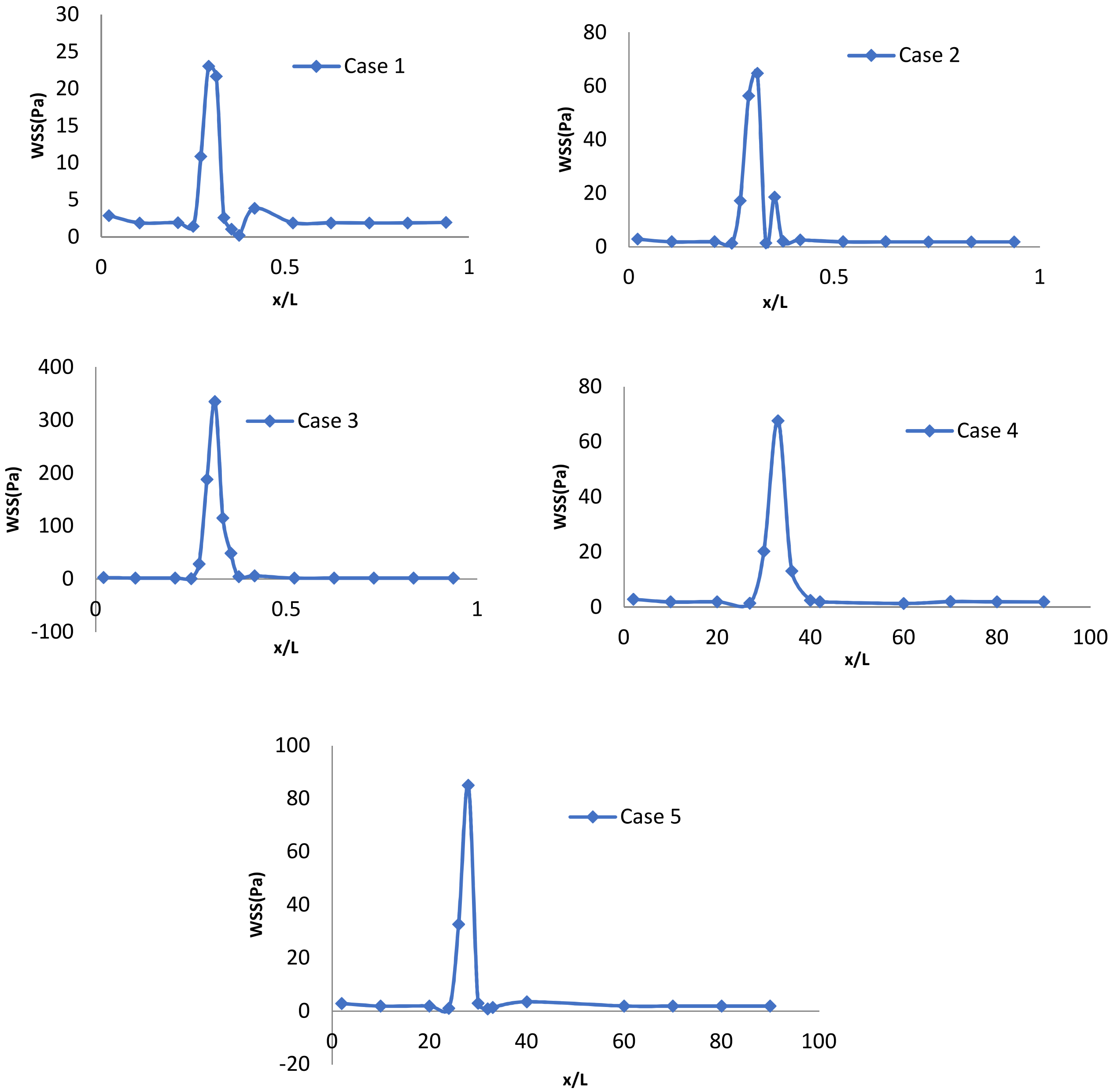

Fig. 10. Influence of wall share stress distribution for all case with respect to axial distance

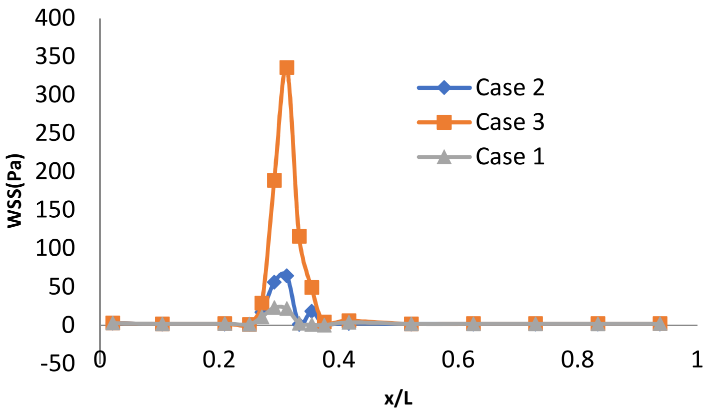

Fig. 11. Comparison of WSS for case 1, case 2 and case 3

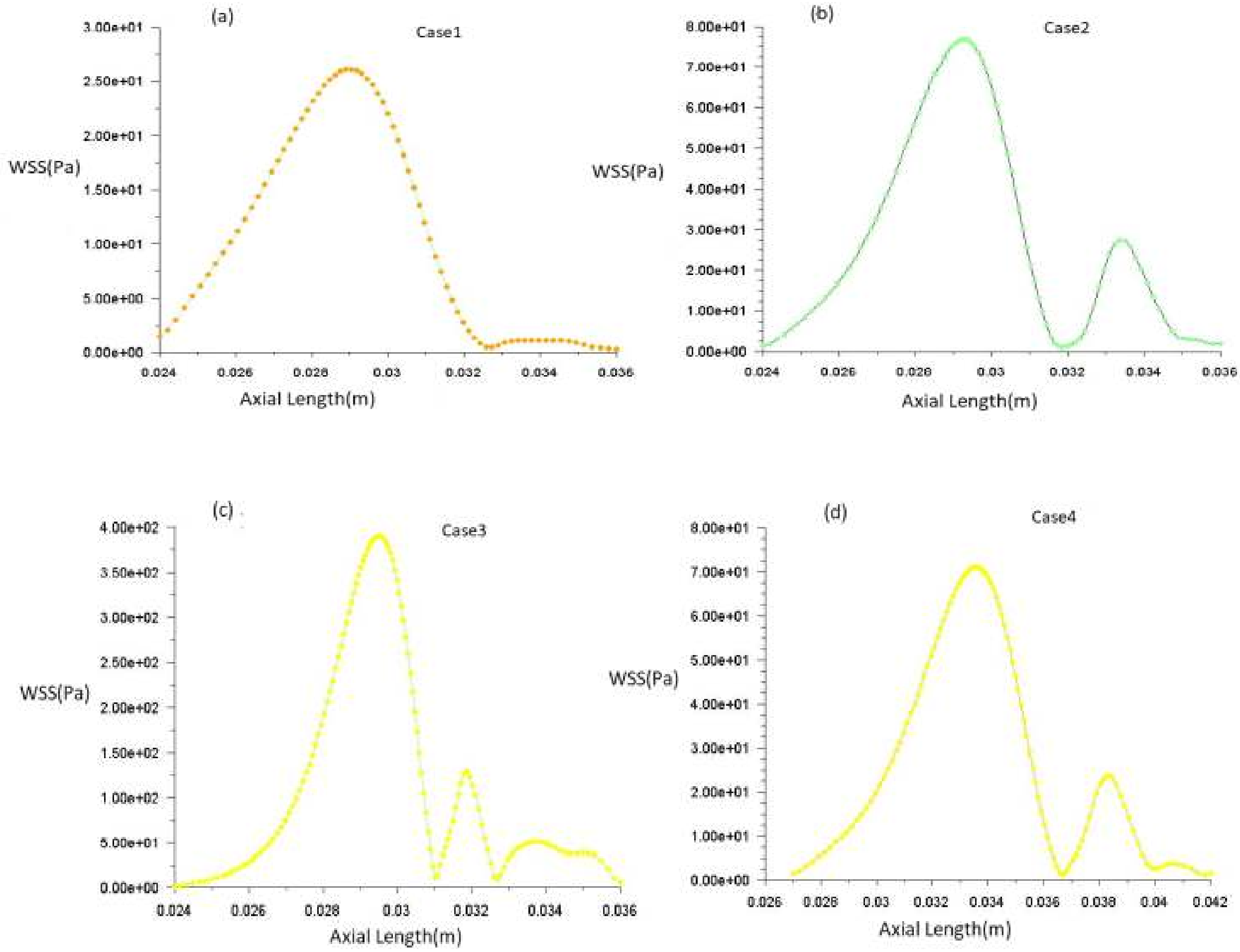

Fig. 12. Effect of WSS distribution at throat region for case1, 2, 3 and 4

6.3 Effect of Velocity Distribution

The figures 13 represent the velocity profile through the entire artery and from the graph it is clear that at throat section the velocity is very high like WSS because of decrement of pressure at this section on the other hand figure 14 indicates the comparison of velocity distribution for case 1, 2 and 3 from where it is shown that case 3 shows more increment of velocity compare to other that’s means increased stenosed area through height is causes the reason of increment of velocity at the profile and at the top point of throat the velocity become maximum and it is the peak point.

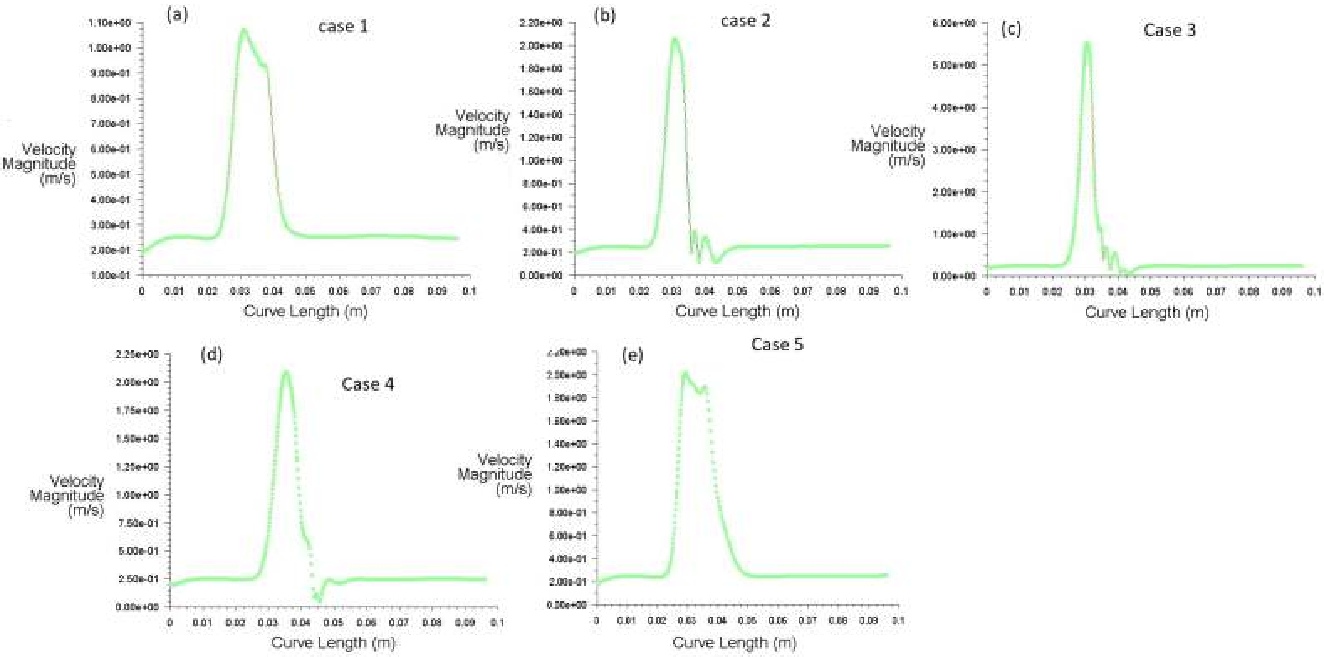

Fig. 13. Effect of velocity distribution for all case with axial position

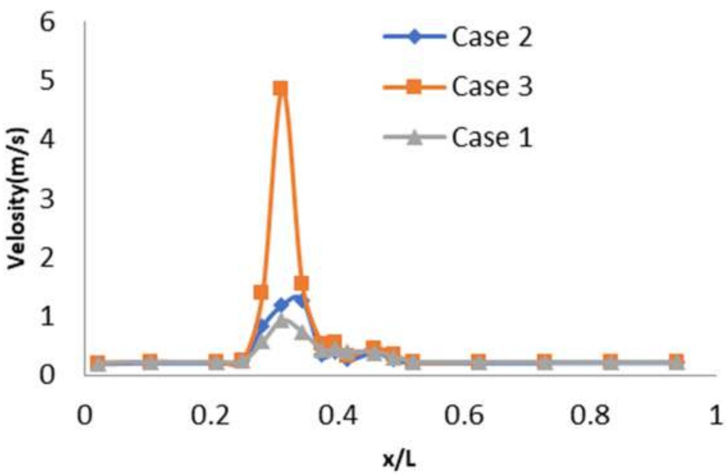

Fig. 14. Comparison of velocity distribution for case 1, 2 and 3

7 CONCLUSION

In the present study for different dimension of stenosis the result and calculation has been shown above and from the above results it is conclude that stenosis in an artery decrease the pressure and increase the WSS and velocity very high and because of these different coronary artery diseases. And from the results to analysis the five cases of dimension it is also conclude that the more the increment of throat height at constant length at x-axis causes the more increment of WSS as well as velocity profile and decrement of the pressure at the throat section compare to after and before throat section and this phenomena also decrease the pressure and increase the WSS and velocity at the before throat section compare to after throat section and on the other hand the more the increment of length of throat at constant height at y- axis causes the less decrement of pressure and less increment of WSS and velocity compared to the previous condition. And by analysis we get more increment of WSS and velocity and more decrement of pressure at case 3 and less at case 1.

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