A Review of Study of the Effects of Plaque Deposits on the Blood Flow through Human Artery

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Abstract -The nature of blood flow changes from its usual state to a distributed flow condition due to the presence of a stenosis in the artery. Atherosclerotic disease tends to be localized and results in a narrowing of the artery lumen due to plaque deposits (known as a stenosis) which causes severe reduction of the blood flow. This can lead to heart attack or stroke which are the major causes of mortality worldwide. Therefore fundamental understanding of any arterial disease is very important because it helps in the diagnosis and treatment of disease. The methods namely experimental, numerical (computational) and analytical is available to tackle the problem of blood flow through stenosed artery. Here in this paper, previous works in numerical and analytical fields related to blood flow through stenosed artery are summarized and the results of previous analysis are also discussed. The result of previous study enhances our understanding of the hemodynamic characteristics in a compliant stenosed artery. This information of blood flow and its behavior could be useful in the development of new diagnosis tools for many arterial diseases. Now days the application of the computational techniques (CFD) has become an important tool in the investigation of the blood flow in artery.

Keywords: Computational fluid Dynamics,Stenosis, Plaque deposits, Hemodynamic characteristics

NOMENCLATURE

MRI: Magnetic Resonance Imaging

CFD: Computational Fluid Dynamics

S: Percentage stenosis

FSI: Fluid- Structure Interaction

I. INTRODUCTION

The human blood consists of formed elements that are suspended in plasma.About 45% by volume of whole blood consist of formed elements and about 55% of plasma in the normal human blood. The formed elements of blood are red blood cells (95%), white blood cells (0.13%) and platelets (4.9%). Almost all vessels (arteries and veins) carrying blood within the body are flexible, and interactions between an internal flow and wall deformation often underlie a vessel's biological function or dysfunction. Diseases in the blood vessels and in the heart such as heart attack and stroke are the major causes of mortality worldwide. The rheological and fluid dynamic properties of blood and its flow behavior through non-uniform cross-section of the blood vessels could play an important role in the fundamental understanding, diagnosis and treatment of many cardiovascular diseases. The arteries are living organs that can adapt to and change with the varying hemodynamic conditions.

Atherosclerotic disease tends to be localized and results in a narrowing of the artery lumen due to plaque deposits (known as a stenosis) which causes severe reduction of the blood flow as shown in fig.1.The stenosis can cause turbulence in blood and reduce flow by means of viscous head losses and flow choking. Plaque rupture can result in heart attack or stroke and hence understanding the development and vulnerability of atherosclerotic plaques is critically important.The best indicator for surgical treatment of atherosclerosis is the degree of stenosis. For diagnosis of a disease, number of in vivo experimental techniques are available to yield information about percent stenosis but says little about hemodynamic factors like flow rate, wall shear stress, pressure distribution, flow reserve or nature of the plaque. These technique are namely X-ray contrast angiography, Doppler ultrasound, Magnetic Resonance Imaging (MRI), MR angiography etc.

The application of the computational techniques (CFD) has become an important tool in the investigation of the blood flow in artery. This is because, distinct from experimental technique its ability to simulate wall shear stress, velocity and pressure fields in virtual models of the system, predict the outcome of interventions and improve the treatment strategies. Furthermore when compared to experimental investigations, computational methods are often less time consuming and less costly. In this paper the various studiesabout the effects of plaque deposits on the blood flow through human arteries done by researchers in the numerical and analytical manner are summarized.

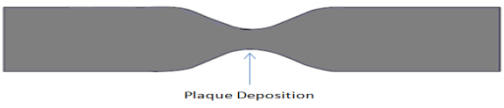

Figure1. The geometric model of the stenosis

II. LITERATURE REVIEW

David N. Ku [1] in his study mentioned fluid mechanics approach for understanding blood flow through human artery. Detection and quantification of stenosis serve as the basis for surgical intervention. Each fluid mechanics aspect plays a role in the generation, detection and treatment of arterial disease. He studied hemodynamics of stenosis. He also mentioned different in vivo experimental techniques (as mentioned in introduction) which are available for diagnosis of disease.

Fuat Yilmaz and Mehmet YasarGundogdu [2] studied Critical review on blood flow in large arteries. The purpose of this study is mainly directed towards present of viewpoints on analysis of blood rheology, blood viscosity models, and physiological flow conditions. Understanding these basics is fundamental to meet the need for a sufficient and reliable CFD model of blood.The blood viscosity models in literature may however be discussed in two main categories namely; Newtonian viscosity models (Lee and Steinman, Einstein) and non-Newtonian viscosity models (power law, carreau, cross). In this study the physical nature of human blood and its viscosity models have reasonably well documented. Mir GolamRabby et al. [3] numerically investigated pulsatile non-Newtonian blood flow through a model (2D) of arterial stenosis using finite volume method. For the non-Newtonian blood flow the Cross model is used along with the Newtonian model. Blood flow is considered unsteady which flows in sinusoidal cyclic nature. Result of analysis shows that in the case of Non-Newtonian blood the flow is always laminar where transient flow is observed in the post stenotic region in the Newtonian case.

Mohsen Mehrabi and SaeedSetayeshi[4]have done CFD analysis of pulsatile blood flow behavior in modeled stenosed vessels with different severities.In this study blood is modeled as an incompressible non-Newtonian fluid which is based on the power law viscosity model and vessel wall as rigid material. Finite Difference method is used taking into account the transient periodic behavior of the blood flow in cardiac cycles.Results showed thathigher percent-area severity of stenosis produces a higher pressure drop, a higher blood speed, a higher shear rate, and a higher wall shear stress.

BahtiyorBuriev et al. [5] studied Fluid-structure interactions of physiological flow in stenosed artery. The geometric models of stenotic blood flow are considered with three different types of constriction of cross-sectional area of blood vessel.Analysis is done using commercial software ADINA 8.4 developed by finite element method. They demonstrated comparisons of the wall shear stress with or without the fluid-structure interaction and their velocity profiles under the physiological flow condition in stenosed artery. The fluid dynamic and vessel mechanical behavior were found to be an axisymmetric from the results for flow velocity and wall shear stress. The wall shear stress rose sharply and declined quickly reversing its direction at the vicinity of the stenosed region is observed.

J.P. Abraham et al. [6] have done unsteady, three-dimensional fluid mechanic analysis of blood flow in plaque-narrowed and plaque-freed arteries.The arterial geometries used for the analysis were determined by the reconstruction of captured in-vivo ultrasonic images. Numerical simulation was used to implement the fluid mechanic model and separate consideration is given to Newtonian and non-Newtonian constitutive equations. The result of the analysis indicates that the removal of the plaque led to an increase in the rate of blood flow both during the systole and diastole portions of the cardiac cycle. The shear stress on the artery wall, a major determinant of the buildup of plaque, is found to be higher for a plaque-freed artery than for a plaque-narrowed artery.

M. Alishahi et al.[7] studied numerical simulation of blood flow in a flexible stenosed abdominal real aorta. The blood is taken as incompressible, non-Newtonian and the arterial wall tissue is treated as isotropic, elastic material with uniform mechanical properties. The software ANSYS Multi-physics was utilized for the numerical simulation of FSI between the arterial wall and blood flow in arteries. The results using two models with rigid and flexible walls are presented and compared. Results show that the computed pressure is lower by 15% for the flexible wall model as compared to the rigid and complaint models.

AbsaarUlJabbar et al. [8] have done numerical analysis of pulsatile blood flow around different plaque shapes in human carotid artery.For this purpose threeplaque shapes were considered namely trapezoidal, elliptical and triangular. These shapes are taken with same base, height measurements and same area reduction of 30% in artery. Tuning fork model is used for arterial wall. Various CFD simulations were performed to analyze the effect of different plaque shapes on blood flow. Comparison of results showed that trapezoidal shape of the plaque has more effect on blood flow producing highest flow velocities and wall shear stresses.

SantabrataChakravart and Prashanta Kumar Mandal [9] have done analysis of two-dimensional blood flow through tapered arteries under stenotic conditions. In this study, a mathematical model of non-linear two-dimensional blood flow in tapered arteries in the presence of overlapping stenosis is developed. The vascular wall deformability is taken to be elastic while the flowing blood is treated to be Newtonian. The presented analytical treatment bears the potential to calculate both the axial and the radial velocity profiles with low computational complexity. The computed results are found to converge at a high rate with the tolerance of $\sim 10^{-14}$ and agree well with the corresponding existing data.

Sanjeev Kumar and ChandrashekharDiwakar [10] developeda mathematical model of power law fluid with an application of blood flow through an artery with stenosis. In this model they considered artery as axisymmetric circular cylinder and blood flow within

this axially symmetric stenosed artery. The governing equation for laminar, incompressible and non-Newtonian fluid (power law fluid) flow subject to the boundary conditions is solved numerically. The analytical expressions for pressure drop, flow rate and wall shear stress have been obtained. Here in this investigation it is observed that if the height of stenosis is increased then the pressure drop and flow rates are also increased.

Jonghwun Jung and Ahmed Hassanein [11] studied three phase CFD analytical modeling of blood flow. This three phase CFD approach including plasma, RBCs, and leukocytes was used to numerically simulate the local hemodynamics (like WSS, Phase distributions and flow pattern for each phase) in flow regime. The non-Newtonian viscosity model was applied to wide physiological range of hematocrits, including low shear rates. The results show that higher leukocytes concentration was correlated with relatively low WSS, near the stenosis having high WSS.

Alvaro Valencia and Martin Villanueva [12] studied unsteady flow and mass transfer in models of stenotic arteries considering fluid- structure interaction. Symmetric and non-symmetric stenotic cerebral arteries models were considered for the numerical study. The Carreau non- Newtonian model is used to describe the variation of normal blood viscosity with the shear rate. Various hemodynamic factors as well as effects of inlet boundary conditions (such as pressure inlet or velocity inlet) are studied in details. It is observed that inlet boundary condition of pressure is critical to obtain realistic hemodynamic results in stenosed artery. The model of stenosed artery with rigid walls is not realistic, because artery is considerably dilated and compressed in one cardiac cycle.

There are various techniques available to study blood flow through stenosed artery. These techniques include experimental, analytical and numerical (computational). Now days CFD simulation of blood flow became the cutting edge tool to investigate cardiovascular dysfunction. Here in this paper, work done by researchers on blood flow through stenosed artery in numerical and analytical fields is summarized and the results of their study are also discussed. For that purpose present study is divided into number of parts according to scope of particular analysis done by researcher.

III. NUMERICAL ANALYSIS CONSIDERING BLOOD AS NON-NEWTONIAN FLUID AND ARTERIAL WALL AS RIGID MATERIAL

Mir GolamRabby et al. [3] numerically investigated pulsatile non-Newtonian blood flow through a model of arterial stenosis. The assumption of Newtonian behavior of blood is acceptable for large arteries because of high shear rate flow. When shear rate is low which are the case of small arteries and the downstream region of the stenosis, the Non-Newtonian behavior of blood flow is acceptable. Generally critical value of limiting shear rate about $100s^{-1}$ is used for addressing transition from non-Newtonian to Newtonian viscosity character of blood. For the non-Newtonian blood flow the Cross viscosity models is used along the Newtonian model and simulation is done for Re=300. The arterial wall is considered as rigid solid material. The geometry of 2D pipe is a one-sided cosine-shaped plaque deposition on the wall. Finite volume approaches are used to discretize the partial differential equations to yield a system of linear algebraic equations. Overall the developed code is second order accurate in both time and space [3].

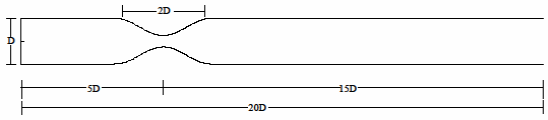

Figure2. Schematic diagram for the model arterial stenosis [3]

Fig.2 shows the schematic diagram of arterial stenosis in terms of 75% reduction of diameter. Here the diameter of artery is D and the length of stenosis region is 2D. The results of analysis are discussed below.Fig. 3(a) describes the wall pressure distribution. Here, the dotted line refers to non-Newtonian and the solid line refers to Newtonian case. As we see the graph from pre stenotic region to post stenotic region, we find a sudden acute drop in pressure at stenotic point for both cases. But the Newtonian flow has a slightly larger drop than the non-Newtonian flow. Wall shear stress, another quantity is shown in Fig.3 (b). At the center of the stenosis, the wall stress is maximum for both the Newtonian and Non-Newtonian cases. However, from the graph we can noticeably see that non- Newtonian wall shear stress is very higher than Newtonian case at the stenosis place. However, both the figures show that when it goes far from stenosis non-Newtonian, wall share stress is steady and it gives a fixed value of wall share stress. Result of analysis shows that in the case of Non-Newtonian blood the flow is always laminar where transient flow is observed in the post stenotic region in the Newtonian case. At the post stenotic region the flow recirculation is created due to the adverse pressure gradient [3].

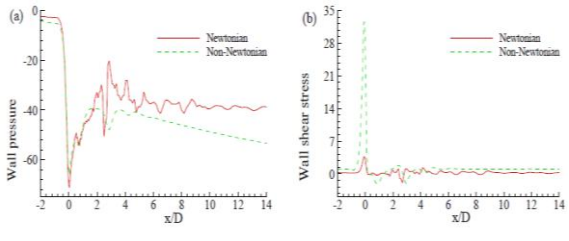

Figure3. (a) Wall pressure (b) wall shear stress for the Newtonian and non-Newtonian blood [3]

Mohsen Mehrabi and SaeedSetayeshi [4] have done CFD analysis of pulsatile blood flow behavior in modeled stenosed vessels with different severities. In this study simulation model is developed to study the unsteady, periodic blood flow through a stenotic artery

of different severity. Blood is modeled as an incompressible non-Newtonian fluid which is based on the power law viscosity model. Also,pulsatile blood flow in the stenosed vessel is based on the Womersley model. Blood flow is governed by continuity equation and Navier-stokes equation. In this study, the stenosis shape is cosine by using Tu and Devil model. Using the straight tube having three different sizes of stenosis, 30%, 50%, and 70% (% area constriction), numerical simulations is carried out for the flow field based on the finite difference method [4].

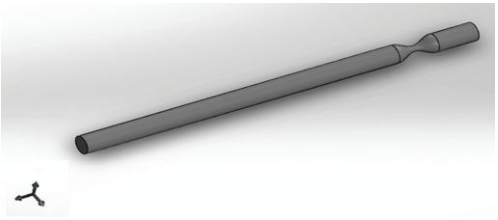

Figure4. The 3D simulation model of the stenosed vessel[4]

The solutions were computed for five cardiac cycles to ensure reproducibility of the pulsed characteristic flow. The heart ejects and fills with blood in alternating cycles called systole and diastole.Combined systole and diastole is called as one cardiac cycle. Therefore blood flow through artery is unsteady and blood flows in a sinusoidal cyclic nature (Cardiac cycle). Generally time period of one cardiac cycle is 0.7 to 0.9 s (Heart beat).Results shows that upstream from the stenosis, the velocity profile in the z-direction is parabolic as shown in Figure 5, and the fluid passes through the stenosis at high speed, especially at the throat of the stenosis. Downstream from the stenosis region, the distal part, the flow has stair-step shape profile, and the longitudinal velocityis negative (along the negative z direction) in the recirculation region.

Higher area blockage severity leads to larger pressure dropping around the stenosis and consequently gives higher speed in the stenosis area. The results also show a similar pattern in the pulsatile velocity, in the pulse pressure, and in the variation of shear rate in cardiac cycles. These confirm the features of the characteristic of the periodic motion. Therefore, in the presence of a narrowing vessel lumen with different area severity, the flow experiences resistance, which causes an increase in the shear stress and in the pressure drop. Higher percent-area severity of stenosis produces a higher pressure drop, a higher blood speed, a higher shear rate, and a higher wall shear stress [4].

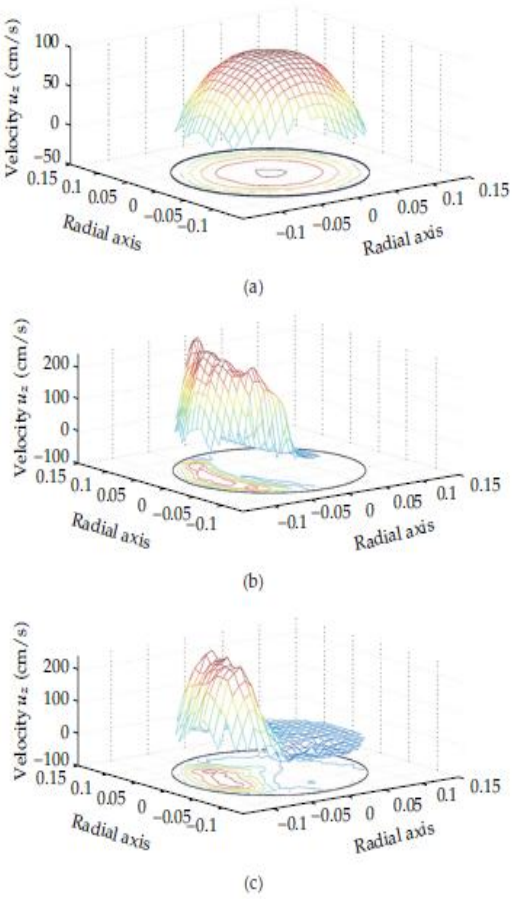

Figure5. The velocityat the peak of systole in plane of the 70% stenosis tube: (a)at the upstream cross-section, (b)at the throat cross-section and (c)at the downstream cross-section [4]

IV. NUMERICAL ANALYSIS CONSIDERING BLOOD AS NEWTONIAN FLUID AND ARTERIAL WALL AS FLEXIBLE MATERIAL

BahtiyorBuriev et al. [5] studied Fluid-structure interactions of physiological flow in stenosed artery. The study is concerned with physiological flow both in elastic and rigid wall vessels with 25, 50 and 75% constriction of cross-sectional area in stenosed arteries. The objective of this study is to understand how the flow features and wall shear stress field change with the development of stenosis by numerically analyzing the interactions between a blood flow and a stenosed wall. The blood is assumed to be incompressible, laminar and Newtonian fluid, while the blood vessel wall is isotropic and elastic.Analysis is done using commercial software ADINA 8.4 developed by finite element method. The diseased artery was modeled as an axisymmetric stenosis with 25%, 50% and 75% area reductions as shown in Fig. 6, respectively. Two cases were studied here: physiological flow model with rigid wall assumption (No FSI model in Fig. 6 (a)), and physiological flow with an elastic wall (FSI model in Fig. 6 (b)). In this study the mean velocity, u=0.33m/s,

corresponding to Re=400 is applied. The results can be compared at five different times of the cycle because there is time variation of mean velocity for the physiological pulsatile flow [5].

Results of analysis are discussed below. Fig. 7 shows the axial velocity profiles of the flow at five different times at the location x'=1 of 25%, 50% and 75% stenosis. As the flow rate with time is increased under the same stenosis rate, the peak velocity profile at the centerline is increased. The size of the recirculation region at point B of 75% stenosis case is approximately 1.4 times larger than at 50% stenosis one when compared Figs. 7(b) and 7(c). In the axial velocity profiles of No FSI and FSI models were compared, and results of velocity profiles were very much same for both models. However, the differences between two models were found to be greater in the reversed flow period.

Recirculation zones were carefully calculated by using negative wall shear stresses, which occurred down side of stenosed region. The wall shear stress rose sharply and declined quickly reversing its direction at the vicinity of the stenosed region is observed. Fig. 8 shows plotted recirculation zones with different percentage of stenosed rate cases. When stenosis rate increased from 25% to 75% stenosed rate, recirculation zone gradually occurred longer and thicker. The most recirculation zone occurred at 75% stenosed rate case at the vicinity of the stenosed region.

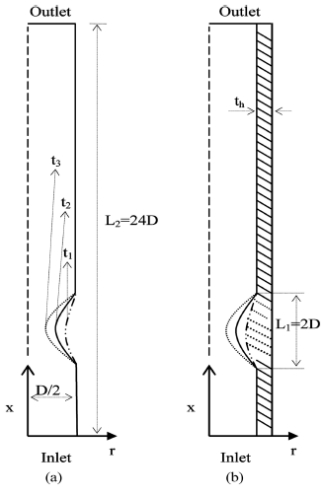

Figure6. Schematic geometries of the stenosed blood vessel (a) with rigid wall model (No FSI Model), (b) with elastic wall model (FSI Model)[5]

Wall shear stress distributions along the axial direction presented at 5 different times in the cycle as shown in Fig.9. Maximum wall shear stress occurred at point B (t=0.16s) at the throat of the stenosed region while minimum wall shear stress occurred at point D (t=0.42s). Furthermore, point C indicates how the wall shear stress rapidly declined with time variation at 25%, 50% and 75% stenotic rates cases. As expected, the largest pressure drop is occurred at the time of peak flow. The pressure drop is the largest when the stenosis rate is 75%

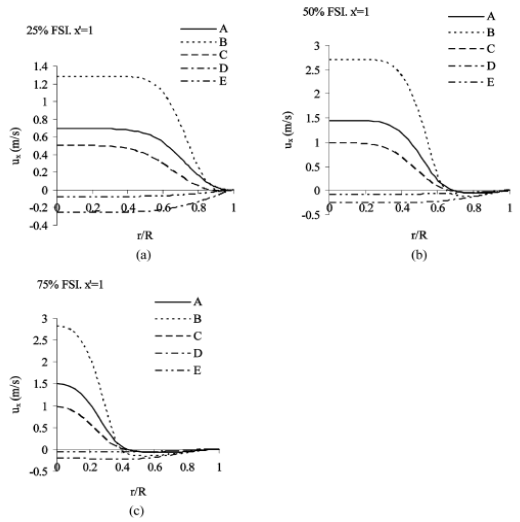

Figure7. Comparison of axial velocity profiles between the No FSI and FSI models at normalized post-stenotic distance of x' =1 [5].

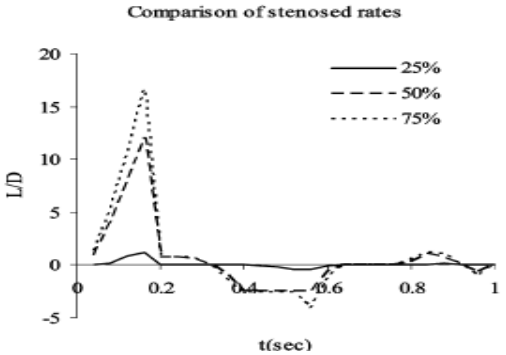

Figure8. Recirculation zone with time variation at different stenosed rates [5]

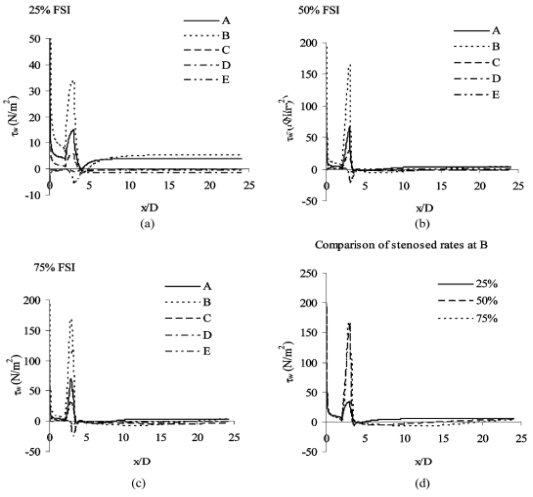

Figure9. Wall shear stress distributions with time variations at different stenosed rates[5]

V. NUMERICAL ANALYSIS CONSIDERING DIFFERENT PLAQUE SHAPES

AbsaarUlJabbar et al. [8] have done numerical analysis of pulsatile blood flow around different plaque shapes in

human carotid artery. Plaques can be punctual (eccentric) or circumferential (symmetrical).In this study the tuning fork model of carotid artery was used. For this purpose three plaque shapes were considered namely trapezoidal, elliptical and triangular. These shapes are taken with same base, height measurements and same area reduction of 30% in artery. All plaques are at same location in carotid artery, i.e. at outer wall of sinus as shown in Fig. 10. Simulations were performed on FLUENT [8]. The flow was assumed to be incompressible, laminar, Newtonian and transient in case of 2D and steady in case of 3D analysis.

Figure10. Different plaque shapes at the outer wall of sinus [8]

Blood is non-Newtonian fluid having different constituents, but can be approximated as Newtonian fluid for larger arteries. In 2D analysis unsteady velocity at the inlet is considered. Figure 11 shows a cross comparison of average flow velocities measured in 2D case with time step of 0.008s and velocity (m/s) of pulse on horizontal and vertical axis respectively. Comparison of these pulse velocities for different cases revealed that the trapezoidal and triangular plaques produce the highest velocities, which leads to the abrupt flow changes. Complete comparison of wall shear stress (3D steady state case) for different plaque shapes is shown in the Fig. 12.

Figure11. Comparison of flow velocities measured in 2D case [8]

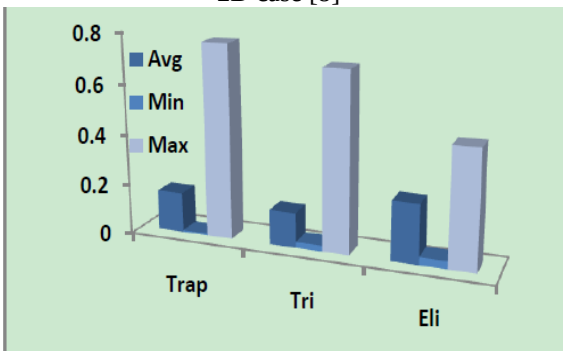

Figure12. Comparison of wall shear stresses with respect to shape of the plaque[8]

The maximum value of wall shear stress was found on trapezoidal plaque while maximum average wall shear stress was found on elliptical plaque because it causes a continuous change in velocity across its surface. Trapezoidal plaque not only caused a highest wall shear stress but also developed lowest wall shear stress zone at downstream of deposit. Previous studies show that one of the main factors involved in plaque buildup is low wall shear stress. On the other hand plaque rupture can be due to high shear stress as it causes high flow changes in the vessel. So plaques similar in shape to the trapezoidal plaque may result in more downstream fatty deposit on artery wall. Triangular plaque appears to be the second most severe plaque [8].

VI. MATHEMATICAL ANALYSIS OF BLOOD FLOW THROUGH AN ARTERY WITH STENOSIS

Sanjeev Kumar and ChandrashekharDiwakar [10] developed a mathematical model of power law fluid with an application of blood flow through an artery with stenosis. Blood is taken as non-Newtonian fluid (power law model) in a uniform circular tube with an axially non-symmetric but radially symmetric stenosis. And flow of blood is considered to be steady and laminar. The governing equation for laminar, incompressible and non-Newtonian fluid (power law fluid) flow subject to the boundary conditions is solved numerically. The analytical expressions for pressure drop, flux (flow rate),and dimensionless resistance to flow and wall shear stress have been obtained. The numerical values extracted from these analytical expressions are presented graphically. Here numerical technique is used to solve the analytical results of this model with considering the temperature 25.5^0C. And for this result stress is taken less than $20sec^{-1}$and the diameter of the tube is less than 0.2mm [10]. Schematic diagram of artery with stenosis is given in figure 13.

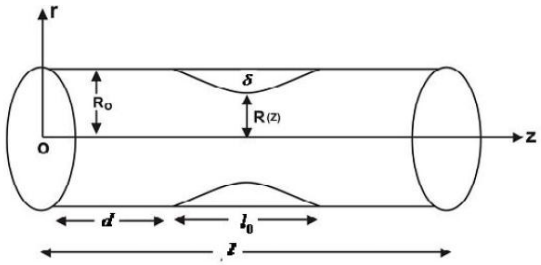

Figure13. Schematic diagram of artery with stenosis [10]

If $R_0$is the radius of artery, δ is the height of the stenosis and R is the radius of abnormal artery. The final equations of the analytical model for pressure drop, shear stress and impedance (resistance to flow) are solved for different values of 'n' (Power law index). And the results are presented graphically as shown in

fig.14 and fig.15.Result based on the mathematical analysis indicates that the pressure drop and flux (Blood flow rate) varying markedly across the stenosis lesion. Here we see that if the size of stenosis increases the pressure drop and flux also increases as shown by figure 14. Figure 15 shows wall shear stress increases and resistance to flow decreases as stenosis size increases.

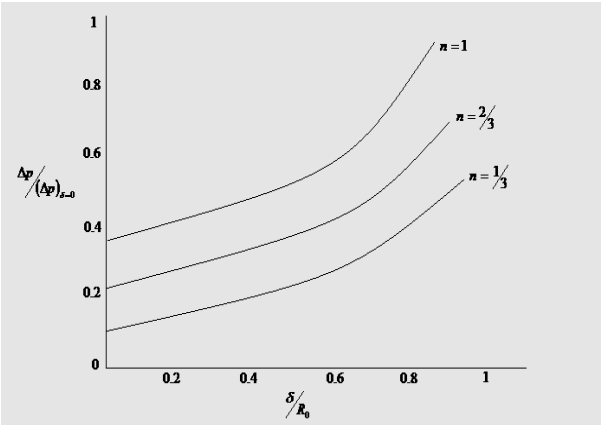

Figure14. Pressure drop across stenosis size for power law fluid[10]

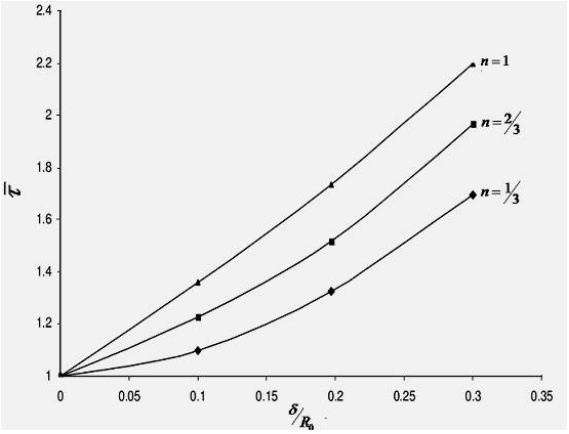

Figure15. Wall shear stress with respect to stenosis size[10]

VII. NUMERICAL ANALYSIS CONSIDERING BLOOD AS NON-NEWTONIAN FLUID AND ARTERIAL WALL AS FLEXIBLE MATERIAL

Alvaro Valencia and Martin Villanueva [12] studied unsteady flow and mass transfer in models of stenotic arteries considering fluid- structure interaction.For the fluid model, the flow was assumed to be laminar, non-Newtonian, and incompressible. The Carreau non-Newtonian model can be used to describe the variation of normal blood viscosity with the shear rate. Physiologically flow condition is imposed using flow measurements with pulsed Doppler ultrasound acquired in the right internal carotid artery for a patient with a stenosis. The time dependence of the inflow mean velocity U(t) in one cardiac cycle is imposed as inlet boundary condition for the 8 simulations considering arterial wall as rigid material. Variation of pressure with the time P(t) at inlet in one cardiac cycle is imposed as inlet boundary condition for the 8 FSI simulations. Simulations are carried out usingcommercial finite element package ADINA. The Finite Element Method (FEM) is used to solve the governing equations.Fig.16shows the domain for the cases with rigid walls and the cases with FSI. Cases with rigid arterial wall or FSI for symmetric and non-symmetric stenosis were investigated for S=50%, 60%, 70% and 80%. The arterial wall has a thickness of 0.24mm, and it is simulated as 3D solid wall [12].

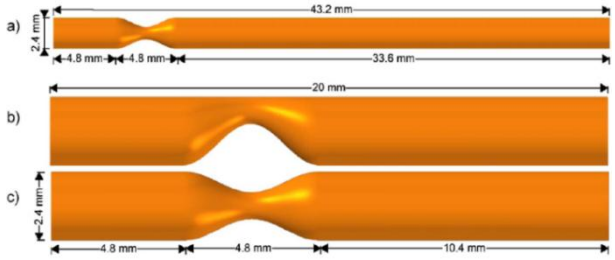

Figure16. Models geometry: a) symmetric stenotic artery with rigid walls, b) non-symmetric stenotic artery with FSI, c) symmetric stenotic artery with FSI. S=60% [12].

Results of rigid model: The time dependence of mean velocity at throat for the symmetric and non-symmetric stenotic arteries modeled with rigid walls and inlet velocity boundary condition are shown in Fig.17. The velocity increases in non-linear form with the stenosis severity and the symmetric stenosis produces higher mean velocity at throat as the non-symmetric stenosis.

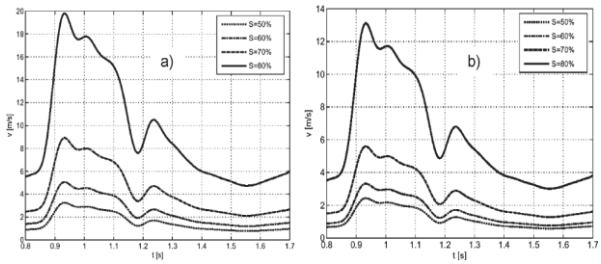

Figure17. Mean velocity at throat versus time with rigid walls: a) symmetric stenotic arteries, b) non-symmetric stenotic arteries [12].

For symmetric stenosis with S=80% the maximal mean velocity is 20 m/s, for non- symmetric stenosis with S=80% the maximal mean velocity is 13 m/s is observed. These values are not realistic from a physiological point of view, and therefore these cases are not representative for the flow in cerebral arteries.

Results of FSI model: The time dependence of mean velocity at throat for the symmetric and non-symmetric stenotic arteries modeled with FSI and inlet pressure boundary condition are shown in Fig.18.

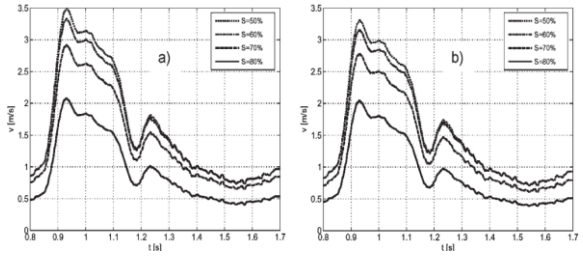

Figure18. Mean velocity at throat versus time with FSI: a) symmetric stenotic arteries, b) non-symmetric stenotic arteries [12]

The velocity decreases in non-linear form with the stenosis severity and with S=80% and 70% the symmetric and non-symmetric stenosis produce similar variation of mean velocity with time. The maximal WSS at throat and the minimal pressure at throat for the symmetric and non-symmetric stenosis are observed. For stenosis severity of S=80% the maximal mean velocity is 2 m/s with a pressure drop of 110 mm Hg. These values are realistic from a physiological point of view, and therefore these cases are representative for the flow in cerebral arteries.

The maximum and minimum artery diameter at inlet are 3,4 mm and 2.3 mm at systolic and diastolic times respectively. The breaking strength of a normal cerebral artery is around 1 MPa. The maximal effective stress at systolic time is around 25% of the breaking strength of the artery. In this study, the effects of the inlet boundary condition are studied in detail. The inlet boundary condition of pressure is critical to obtain realistic hemodynamic results in stenosed arteries with diseases blood condition. The model of stenosed artery with rigid walls is not realistic, because the artery is considerably dilated and compressed in one cardiac cycle. The geometry and severity of the stenosis have effects on recirculation length, wall displacement [12].

Various studies about effects of plaque deposits on blood flow through human artery are summarized. In all studies, researchers compared their results with available experimental oranalytical results about same problem. And results are found in good agreement with it. From the results we are able to know what changes in the hemodynamic factors like WSS, blood flow rate and pressure distribution due to plaque deposits. Previous studies show that one of the main factors involved in plaque buildup is low wall shear stress. On the other hand plaque rupture can be due to high shear stress as it causes high flow changes in the vessel. Vortex blood (At recirculation zone) cannot flow properly and it takes time to reach its ultimate destination [1]. It is noticed that there is sudden rise in blood velocity, shear stress on arterial wall at the throat of stenosis. Maximum pressure drop is observed across the stenosis. And low wall shear stress and recirculation zones are observed at the downstream region of stenosis. Therefore there are possibilities of plaque buildup at downstream region of stenosis and possibilities of plaque rupture at throat of stenosis. Size and shape of stenosis also has a great influence on blood flow parameters (Reduces blood flow drastically). Knowing all this plays an important role in the fundamental understanding, diagnosis and treatment of many cardiovascular diseases.

VIII. CONCLUSION

In this study, effects of the plaque deposits on blood flow through human artery are discussed. This study is review of previous work related to blood flow through artery which majorly concern about numerical and analytical work. Practically blood is non- Newtonian fluid and blood flow through artery is characterized as unsteady state, periodic phenomenon. Various studies of researchers are presented here with different assumptions related to blood, blood flow, arterial wall material and size and shape of stenosis. From the results it is possible to identify the locations of low wall shear stress, high velocities, maximum pressure drop, and recirculation zones in arteries. According to that regions of plaque buildup and plaque rupture are located. This helps in the generation, detection and treatment of arterial disease. Now days CFD simulations along with the in vivo experimental techniques is used for diagnosis of arterial disease. CFD simulation of blood flow has become the cutting edge tool to investigate cardiovascular dysfunction and has great scope in future.

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