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CFD ANALYSIS OF BIFURCATED ARTERY WITH VARIABLE PARAMETERS

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Abstract
Cardiovascular disease (CVD) continues to be a top health concern worldwide, frequently developing when fat, cholesterol, calcium, fibrin and wastes collect on artery walls. If blockages remain untreated, they may result in heart attacks, strokes, hypertension and sudden cardiac death. The complex design of bifurcated arteries puts them at risk of both wrong flow and the formation of plaques. The goal of this study is to see how the angles at which arteries split influence blood movement within them using Computational Fluid Dynamics (CFD). It examines wall stress, velocity and pressure in the presence of both Newtonian and non-Newtonian pulsatile flow conditions. The bifurcated artery model was first developed with SolidWorks and then analyzed using Ansys Fluent to examine how the shape of the bifurcation (angles of 35°, 50°, 65° and 75°) influences wall shear stress, velocity and pressure. At the outset, simulations were carried out for steady-state situations, treating blood as Newtonian and applying the energy equation to keep body temperature at 37°C. Non-Newtonian behaviour was captured and blood's ability to thin under shear stress was modelled, after which pulsatile flow was used to correctly represent the dynamic cycles of the heart. The results suggest that higher bifurcation angles are connected to lower wall shear stress, reduced blood flow, greater pressure and more flow disturbances. It becomes clear from pulsatile flow that the blood takes longer to accelerate and loses more energy as the angulation increases. Analysis using a mesh with sensitivity revealed that results are fully resolved at 0.1 mm or higher. The study points out the important effects of arterial walls and blood flow properties on blood circulation and gives useful information for improving cardiovascular tests, estimating disease development and planning better vascular treatment approaches.

INTRODUCTION

A leading cause of death globally is coronary artery disease (CAD) [1]. With coronary artery disease (CAD), atherosclerotic plaques build up inside the coronary arteries, narrowing them and lowering blood flow. In many cases, this gradual plaque buildup happens before acute coronary syndrome (ACS) manifests [2, 3]. Bifurcation lesions are still difficult to treat with percutaneous coronary intervention (PCI), and the death rate is much higher than for non-bifurcation lesions[4]. Hemodynamic assessment integration significantly improves ACS risk prediction and makes it easier to provide high-risk patients with the best care possible [5, 6]. In stenotic arteries, low wall shear stress (WSS) occurs both upstream as well as downstream of the stenosis, which can occasionally cause flow separation, whereas high WSS is typically seen at the stenosis throat. Bifurcation flow patterns, especially low WSS areas and vortexes, are linked to the development of atherosclerosis [7, 8]. WSS-derived metrics are frequently used to assess an artery's atherosusceptible areas. In particular, the amount of wall shear stress across a cardiac cycle is measured by time-averaged WSS (TAWSS). While higher TAWSS values may cause endothelial damage, lower values have been linked to the promotion of atherosclerosis [9, 10]. Another important consideration is flowing reversal, which is measured by the oscillatory shear index (OSI), which was first proposed by Ku et al. [11] to measure changes in the cycle-averaged shear stress vector's direction under pulsatile flow. The development of atherosclerotic plaques and decreased WSS are correlated with elevated OSI levels [12]. From the standpoint of fluid dynamics, there are notable disruptions to the flow in this area. According to existing research, flow separation as well as recirculation are essential for platelet thrombus formation and the early onset of atherosclerotic plaques [13].

An improved analytical examination of the complex interactions between vascular disease and hemodynamics has been made possible by the application of computational fluid dynamics (CFD), which has proven crucial in the study of hemodynamics at the common carotid bifurcation. This novel method has become increasingly well-liked in hemodynamic research because it provides comprehensive insights regarding blood flow properties and associated phenomena. Researchers can uncover the root causes of cardiovascular disorders by Modeling and analyzing the complex fluid dynamics surrounding the carotid artery bifurcation using computational fluid dynamics (CFD). The application of CFD in hemodynamic research offers a thorough framework for analyzing hemodynamic variables, flow patterns, as well as distributions of wall shear stress that are strongly linked to the onset and progression of vascular illnesses [14, 15]. Instead of being a straightforward tube, the carotid artery has a complex structure with several twists, branches, and segments of varying widths. Blood flow via an artery is influenced by its geometry. One of the main mechanical factors at play is the shear stress that blood flow produces on the artery wall. The force acting parallel to the vessel's wall is known as shear stress. Blood undergoes changes in flow velocity as well as pressure as it passes through the carotid artery, which is curved and irregularly shaped. Shear stress varies along the artery wall because of these changes in flow dynamics. Atherosclerosis invocation along with bifurcation geometry with distinct structures, like the division of the common carotid artery (CCA) towards daughter arteries of different size, structure, as well as branching angle (the angle between the internal carotid artery (ICA) as well as external carotid artery (ECA)), have been closely linked in several studies [16]. Tada [17] investigated how altering the bifurcation angle affected the distribution as well as level of both WSS at the carotid bifurcation's atherosclerotic lesion site. Their results showed that the distribution of WSS and the dimensionless oxygen wall flow were significantly impacted by changes in the bifurcation angle. Nevertheless, it was found that the axial flow pattern was only little affected by altering the bifurcation angle.

Using six simulation cases with different body accelerations and bifurcation angles, Ro and Ryou [18] carried out a numerical analysis that focuses on the properties of blood flow in a stenotic artery bifurcation when subjected to human body acceleration. The goal of the analysis was to ascertain how these variables affected flow rate and wall shear stress, and the findings showed that increasing body acceleration increased both flow rate and wall shear stress. Momin et al. [19] investigated the impact of hematocrit (Hct) level and bifurcation angle on the start of atherosclerosis using three distinct left carotid artery geometries with angles of 40°, 48.5°, and 63.5°. Additionally, the study discovered that WSS values were higher for models with narrower angles and lower for models with wider angles. To improve previous studies on coronary artery hemodynamics, Müftüoğulları et al. (2024) [20] examined how angles at bifurcations (30°, 75° and 120°) affect blood flow and related measures like wall shear stress (WSS), oscillatory shear index (OSI) and pressure in an idealized main branch of the left coronary artery with half an obstruction in all primary branches (LM, LAD, LCx). The authors used CFD and the Carreau blood flow model to show that raising the angles of arterial branches caused a more unbalanced blood flow, more areas of re-circulation and higher odds of plaque build-up. These observations fit well with previous studies connecting disruptions in flow patterns and artery disease, while pointing out that helical patterns emerge as velocity goes up. Despite using basic models and conditions, the research delivers useful contributions to earlier research on the effects of arterial structure on the heart's risk factors. A direct correlation between a wide BA and dimensions changes downstream of the lesion was found by Sun and Cao (2011) when they analysed computed CT angiography images of 22 individuals with left main disease [21].

Finally, Beier, Susann, et al.[22] investigated for both non-stented and stented bifurcations, the hemodynamic impact of Y-shaped BA between 40°, 60°, and 80° revealed slight alterations of unfavourable hemodynamic thresholds throughout the cardiac cycle. This implies that stent placement and other artery shape characteristics (such asymmetrical, diametric, or entering angle) may create flow patterns important for the onset and progression of atherosclerotic disease. Bifurcation angles and stenosis in the coronary arteries were studied by Zaman et al. (2020) using both idealized models and computational fluid dynamics. Blood flow was blocked more and FFR was reduced in those with big bifurcation angles (93°) and high stenosis severity which showed more serious CAD. The results suggest that the shape of arteries plays a major role in how CAD develops and that CFD is a suitable method for analyzing these vascular changes[23]. For hemodynamic research to be accurate in stenosed and bifurcated arteries, using non-Newtonian models of blood flow is important. Using a computer simulation and the Carreau model, Amiri et al. (2019) [24]showed that assuming non-Newtonian flow effects gives higher peak velocities and wall shear stress for blood. Sharper angles at artery bifurcations were found to make the flow more unstable and increase the range of stress changes. These outcomes stress that both alternative flow laws and proper shapes of the vessels matter for realistic blood flow simulations. As shown by Jamali and Ismail (2019), a narrowed artery bifurcation brings changes in temperature around the area where blood currents keep traveling backward. Different types of flow can happen due to Reynolds number and these changes can influence disease progression, so they play a big role in hyperthermia treatments [25].

The aim of this study is to model blood flow through a bifurcated artery using CFD across Newtonian and non-Newtonian conditions and with various angles. The method looks at changes in wall shear stress, pressure and velocity to spot disturbances related to vascular diseases and aid in designing stents and surgery planning. The study wants to know at which angles complications in blood flow are most likely to show up. Gaining these results should increase our knowledge of how arterial shape affects disease and its treatment.

Methodology

This study uses CFD to examine how blood flows through an artery model that can be adjusted based on its branches and surrounding conditions. Plans for the model's arteries are made with SolidWorks and differences are applied to branch angle (35°, 50°, 65° and 75°), artery size, length and stenosis to reflect natural conditions inside the body. Next, the models are converted to a grid pattern using tetrahedral grids for good quality mesh, with extra fineness around the vessel surface to consider boundary layer effects and correctly calculate the wall shear stress. Blood is assumed to be an incompressible Newtonian fluid using standard physiological density (1060 kg/m³) and viscosity (0.0035 Pa·s). Appropriate boundaries were set, with a steady or pulsatile blood section at the inlet, normal blood pressure at the outlet and no-slip at the vessel walls. Simulations are run on ANSYS Fluent, the used solver, to solve the continuity and Navier–Stokes equations for stagnant or shifting fluids based on the Reynolds number, until the residual drops below a set value and the solution is stable. Key information about flow, pressure differences and stress near the walls is retrieved using visual tools and this makes it possible to check which parameter combinations could lead to abnormal or disease-sensitive areas in the arteries. Energy analysis was made to include body temperature for Newtonian stead-state blood.

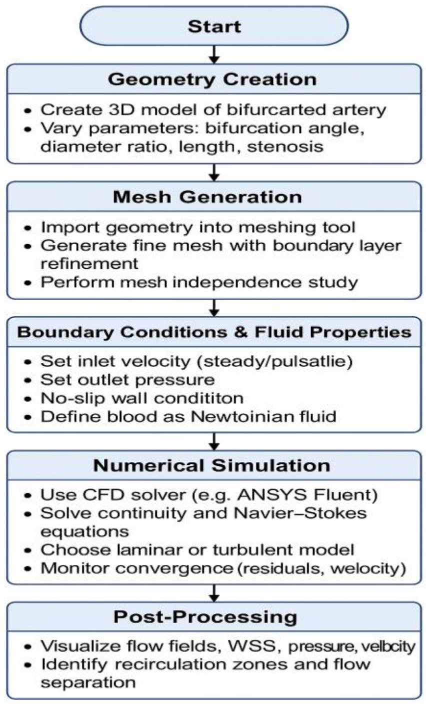
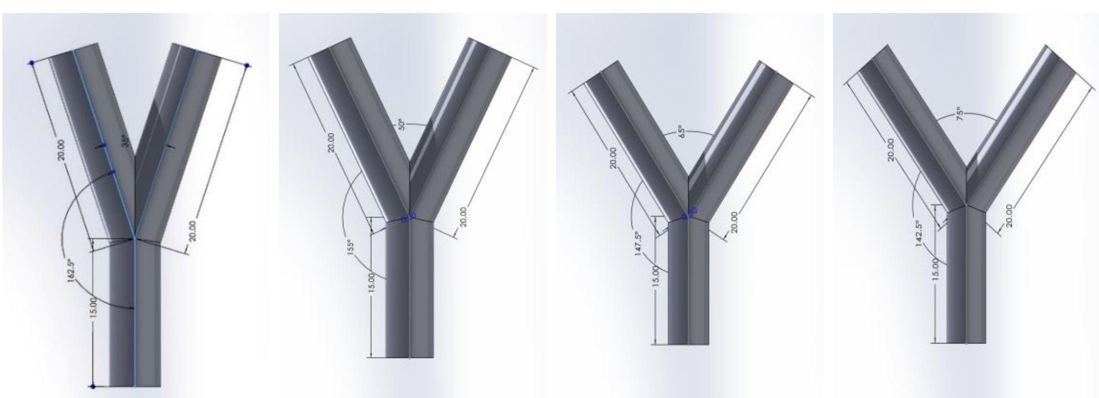


Figure 0.1 Methodological Flowchart

Geometry Creation

SolidWorks (CAD) Software is used to construct a three-dimensional model of a bifurcated artery at the geometry creation phase of CFD analysis. In the model, a central parent artery parts into two daughter arteries and the flow is investigated by varying a set of geometric details. These elements are the angle formed by the branches (35°, 50°, 65° and 75°), the differing diameters between branches, their lengths and any presence or seriousness of stenosis in any area of the artery. The variety in the model means several different anatomic cases can be explored to discover how configurations affect blood circulation.



(a) (b) (c) (d)

Figure 0.2 Bifurcated artery Geometries at Different Angles (35°,50°,65°,75°)

Mesh Generation

To create a mesh in this part, the 3D models of bifurcated arteries are uploaded into Ansys Fluent and converted to a coarse tetrahedral grid, perfect for handling complex arteries. The mesh is made using progressively smaller sizes, decreasing from 1 mm to 0.1 mm to achieve independence of the mesh. This study checks if the simulation outcomes vary strongly due to changes in mesh density. To ensure accurate details and stress calculations in sensitive places, finer grades, 0.3 mm to 0.1 mm are anchored in the bifurcation region and around the arteries. Velocity profiles and WSS are compared on several mesh densities to determine which one balances the accuracy of the solution with how quickly it can be computed, so that the results from CFD are reliable.

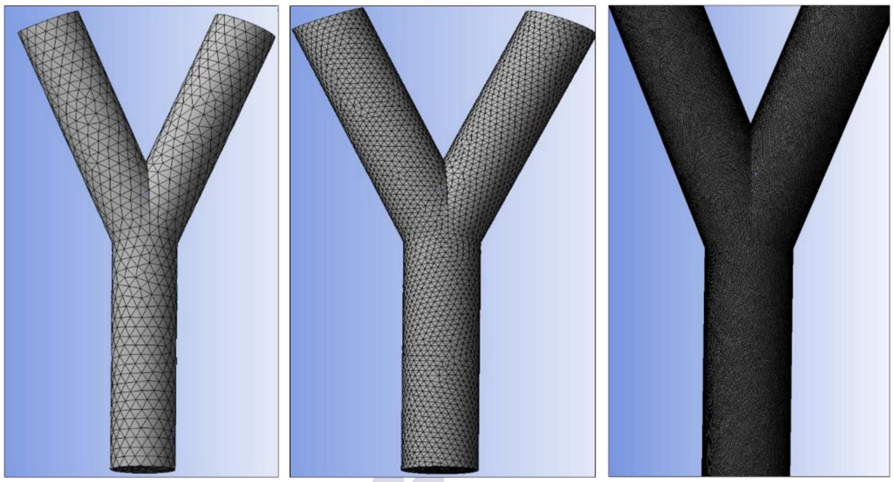

(a) (b) (c)

Figure 0.3 Illustrate the mesh size (a) 1 mm (b) 0.5 mm (c) 0.1 mm

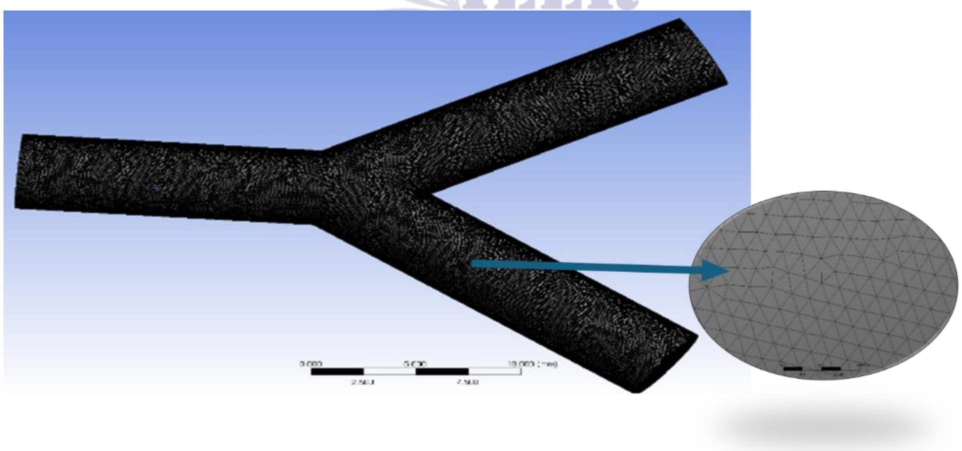


Figure 0.4 Tetrahedral Meshing Model of Bifurcated artery

Boundary Conditions

Realistic blood flow in the bifurcated artery is simulated by applying boundary conditions in ANSYS Fluent. The model begins with a velocity inlet set at 0.17 m/s to simulate blood traveling normally through the artery. At these outlets, a pressure outlet condition is set to 11,597 Pa to reflect common arterial pressure. No-slip conditions and rigidity are applied to the arterial walls, so they cannot be permeated. Blood is considered an uncompressible Newtonian liquid having a density of 1060 kg/m³ and a viscosity of 0.0035 Pa·s.

Continuity equation:

$\nabla.\bar{U}=0, \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}$

Navier –stokes equation:

$\frac{\partial \bar{U}}{\partial t}+\bar{U}.\nabla\bar{U}=-\frac{\Delta P}{\rho}+\mu\nabla^2\bar{U}$

By assuming that the flow in the bifurcation is laminar, the flow can be described by the following governing equations for incompressible Newtonian fluids:

$\frac{\partial u_j}{\partial x_j}=0,$

$\rho\frac{\partial u_i}{\partial t}+\rho\frac{\partial u_j u_i}{\partial x_j}=-\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_i}[\mu N(\frac{\partial u_I}{\partial x_j}+\frac{\partial u_j}{\partial x_i})]$, I, J = 1, 2, 3

Motion of blood in large and medium-sized arteries is modelled by 3D incompressible, nonlinear time-dependent Navier-Stokes equations. This model includes velocity components u_1, u_2, fluid mass density ρ, pressure p, and the viscosity μN of Newtonian fluids. This model combined with a non-Newtonian model is a complete system to simulate blood flow dynamics sufficiently. In given table few boundary conditions for our case of study are specified.

Table 0.1 Boundary Conditions Values

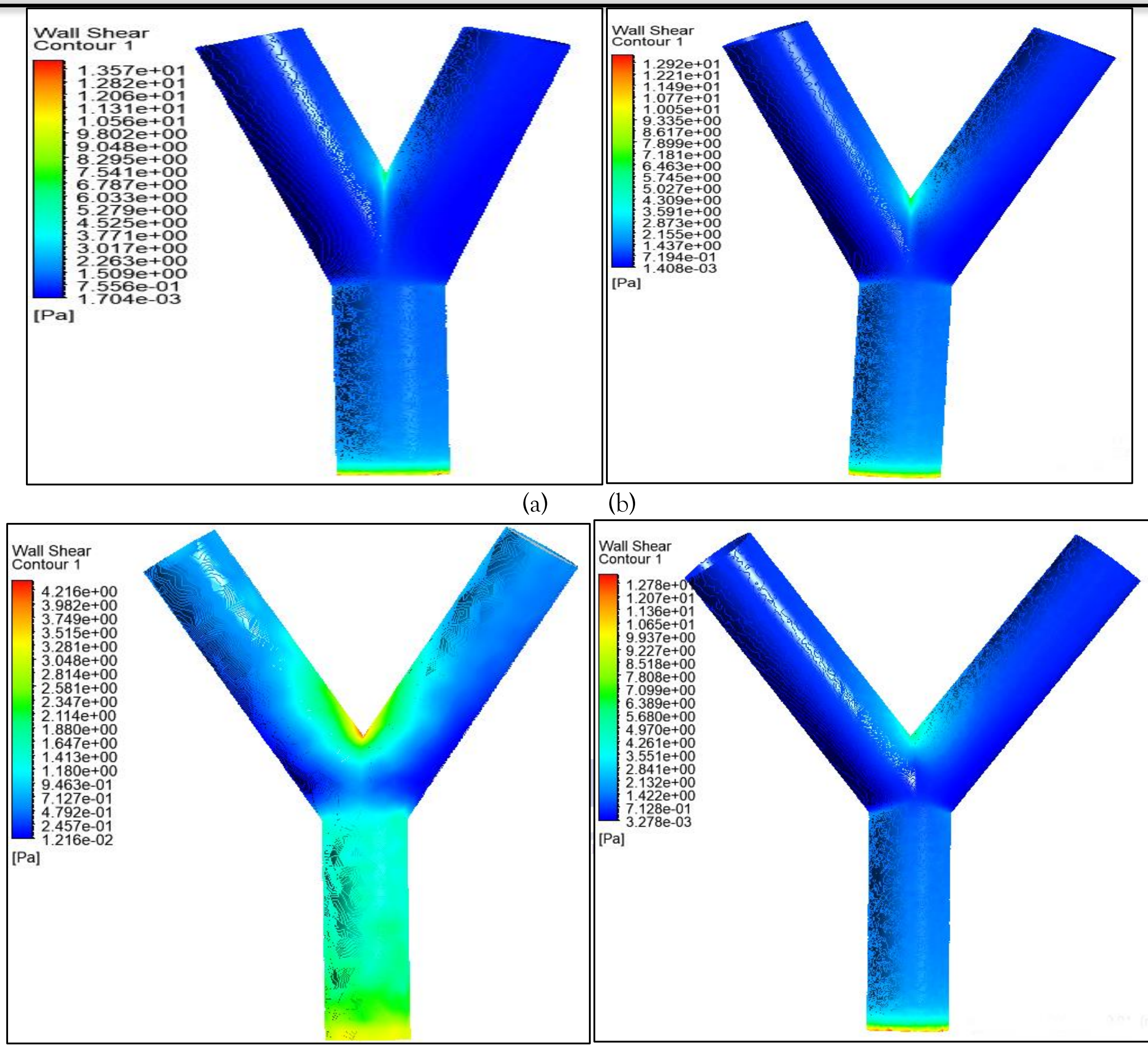
Parameters	Values
Viscosity of blood	1060 kg/m^3
Density of Blood	0.003528 Pa
Outlet Pressure	11,597 Pa
Initial Velocity	O.17 ms^{-1}

CFD Simulation Setup

In the simulation process of blood flow in a bifurcated artery using CFD software ANSYS Fluent the study was set up in a way that which would allow for the best results and accurate outcome. A 3D simulation with "double precision" was used to simulate flow with high levels of detail that captured important flow physics. The usage of six cores alongside one GPU and parallel processing also enabled quicker calculations. A laminar viscous model was chosen from amongst the physiological conditions which imply that the blood flow is laminar and has a low Reynolds number in small and medium sized arteries. Blood properties were assumed according to Newtonian model with density and viscosity of 1060 kg/m^3 and 0.003528 Pa, respectively. Boundary condition comprised inlet velocity of 0.17 m/s, and outlet pressures of 11,597 Pascal's. For realistic blood flow there is a pulsatile blood flow model which was incorporated by implementing C-UDF to include velocity differences. The SIMPLEC solver method was used to avoid coupling between the velocities and the pressures and S second order schemes were used to discretize pressure and momentum equations more accurately. For convergence efficiency, the hybrid initialization type was applied in post-processing there were presented the pressure with the help of streamlines and velocity with the help of contours. For non-Newtonian behaviour, the Carreau model parameters were used, which gives the effective shear thinning nature of blood. They provided the best conditions for correct and fast reproduction of the hemodynamic behaviour in arteries with bifurcations.

Results and Discussion

Simulations were done using CFD to explore the variations in WSS within a bifurcating artery due to changing the angle of the bifurcation 35°, 50°, 65° and 75°. Both elevated and reduced WSS lead to problems in vascular biology, causing endothelial damage and atherosclerosis. Simulation results shown as contour plots highlight how differences in bifurcation angle cause changes in the flow pattern, including changes in velocity, separation points and zonal recirculation. When the angle is 35°, the stream is uniform with low disturbance of the flow, but when you increase it to 75°, the flow becomes more disrupted and has larger low-WSS areas. The differences found guide us in identifying where vascular disease might occur and confirm the impact of arterial geometry on hemodynamics in those regions.



(c) (d)

Figure 0.1 Simulations Model of (a) 35° (b) 50° (c) 65° (d) 75°

Bifurcated artery of angle 35° illustrate the simulation that indicates that WSS values rocket up to 13.57 Pa close to the bifurcation but fall to lower values of around 0.0017 Pa further away from the split and along the barrier on the mental artery branch. Such regions with WSS below 2 dyn/cm are important, as they may cause higher chances of atherosclerosis formation owing to the irregular and fluctuating flow. These results prove that how arteries are formed and the WSS generated play a key role in detecting where problems in blood flow could give rise to disease. As seen in the image of 50°, the wall shear stress (WSS) in a 50° bifurcated artery ranges from 0.0014 Pa to 12.92 Pa, showing that at the bifurcation apex, stress is highest and along the outer walls of the branches, it is lowest, demonstrating disturbed flow patterns. The pattern of asymmetric WSS proves how the shape of the artery is linked to blood flow changes and identifies zones at risk for atherosclerosis. WSS in the 65° bifurcated artery ranges from 0.0216 Pa to 4.216 Pa and can be seen highest at the bifurcation apex. WSS is also relatively low downstream and along wall sections away from the bifurcation. A wider view introduces more flowing disorder which brings more patches of low WSS that can damage arteries. The image of 75º bifurcated artery illustrates that the wall shear stress (WSS) in this bifurcated artery changes from 0.0028 Pa to 12.78 Pa and is highest at the point where the arteries come together. Using a wider angle on the scan leads to more flow disturbance which can make parts of the artery more susceptible to atherosclerosis.

It can be seen from the results that the bifurcation apex experiences the greatest WSS, followed by a gradual decrease along both outer walls and downstream sections. When the angle between the bifurcation branches increases from 50° to 75°, low-WSS regions enlarge, and the flow is disturbed more. It has been found that low WSS areas increase the risk of atherosclerosis, making clear that vessel shape affects vascular well-being.

Sensitivity Analysis on The Bases of Mesh Size

A sensitivity analysis of blood flow is shown in the graph by connecting velocity and mesh size as they change from 1 mm to 0.1 mm. When mesh size decreases below 0.5 mm, blood velocity goes from approximately 2.49 m/s to 2.60 m/s, but at this point the rise is very moderate. Over larger sizes of mesh, blood velocity doesn't improve much more, so finer mesh sizes have a little effect from that point on.

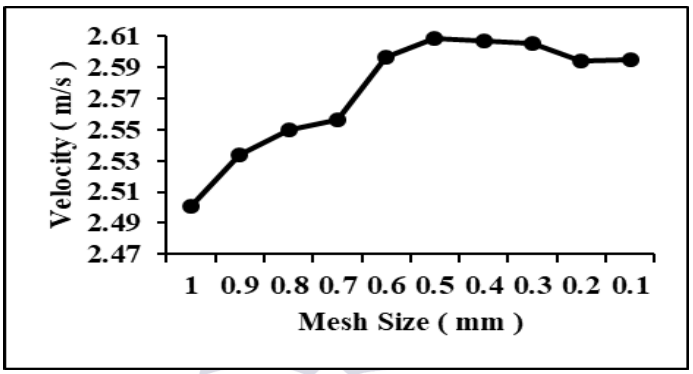


Figure 0.2 Velocity values for Refined Mesh Size

Observation of Static Newtonian Blood Flow

The graph represents how Newtonian blood flow velocity stays the same in loop models with different bifurcation angles of 35°, 50°, 65° and 75°. Velocity is highest at 35° (about 0.261 m/s) and then decreases to its minimum at 65° (around 0.249 m/s) which means that flow becomes more disturbed or difficult at the greater angle. At 75°, the velocity rises a bit more, meaning flow alignment is starting to come back. This shows that, with a Newtonian fluid in a static condition, flow behaviour is most reduced when the bifurcating angle is moderate such as 65°.

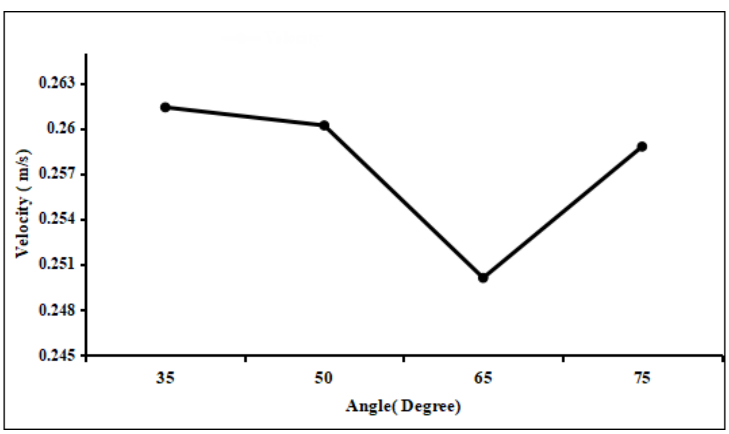


Figure 0.3 Graph between Angles and Velocity

Blood Flow Pressure on Bifurcated arteries

The graph demonstrates the changes in blood flow pressure in bifurcated arteries at different bifurcation angles—35°, 50°, 65° and 75°. The steady pressure at 11,597 Pa for 35° and 50° shows there is very little blockage in these pipelines. Nevertheless, the pressure rises quickly to approximately 11,695 Pa as soon as the temperature reaches 65° and holds this level until 75°. A bigger increase in pressure difference confirms that wider angles in bifurcations—65° and more—generally result in stronger obstacles to flow which occurs likely due to more turbulence and recurrent recirculation in the branches.

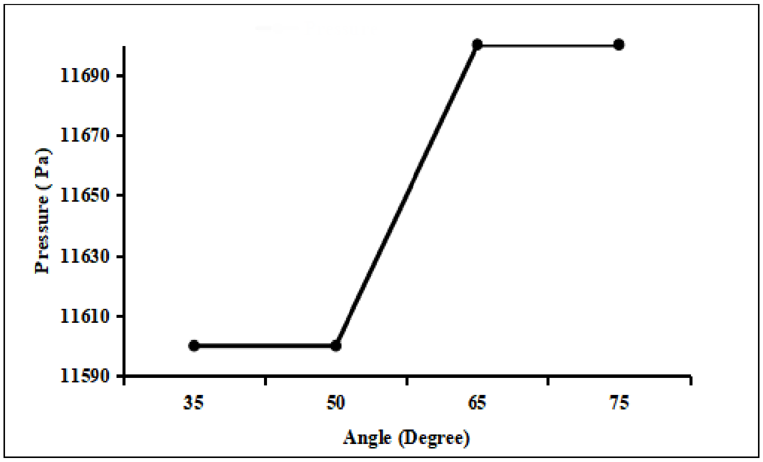


Figure 0.4 Graph between Angles and Pressure

Wall Shear Stress (WSS) on Bifurcated Arteries

The illustration shows how wall shear stress (WSS) varies through arteries that branch at angles of 35°, 50°, 65° and 75°. The strongest and most uniform shear stress, equal to about 13.5 Pa, occurs at 35° and 65° along the wall of the vessel. Flow disturbance or redistribution can be seen when we notice that WSS decreases from 18.8 Pa at 0°C to only 12.9 Pa at 50°C. Flow separation and decreased shear begin at 75°, as the WSS value at that point is 12.75 Pa. This demonstrates that the size of the bifurcation angle influences blood flow near the artery and where stress might appear in the vessels.

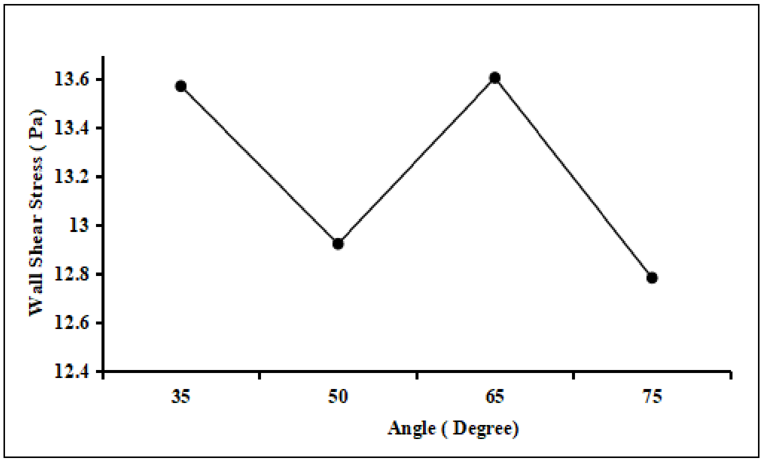


Figure 0.5 Graph between Angles and Wall Shear Stress

Energy Equation for Static Newtonian Blood Flow

This graph shows the relationship between energy-related velocity and angle for blood flow in bifurcated arteries at 35°, 50°, 65° and 75°. If the bifurcation angle is increased, the speed of the liquid slowly decreases—it is 0.2606 m/s at 35° and 0.2583 m/s at 75°. In wide bifurcations, a lower flow rate is observed which may be caused by bigger disruptions and separation of the current. The findings explain the influence of geometry on how energy efficient blood flow is through bifurcated arteries.

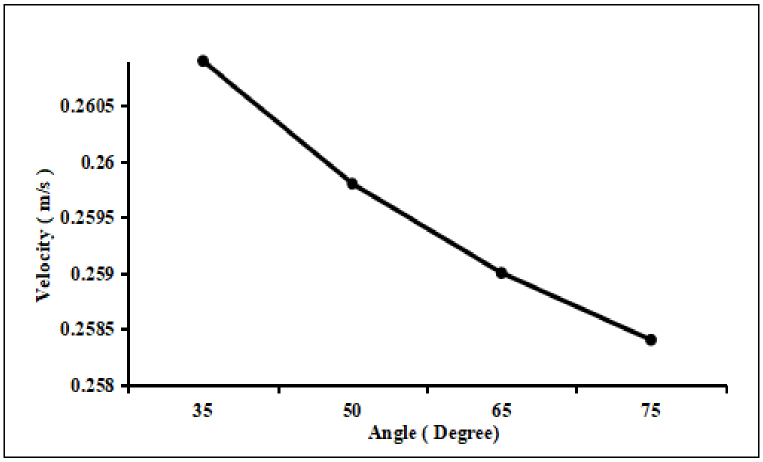


Figure 0.6 Graph between Angles and Velocity

Energy Equation for Blood Flow Pressure

Pressure in the energy of blood flows through narrowing bifurcations can be seen in the graph, with 35°, 50°, 65° and 75° as examples. The value of the pressure stays roughly equal to 11,640 Pa at two angles, 35° and 50° which means there is little resistance and waste of energy. At 65° the pressure raises to 11,649 Pa and won't change further, remaining constant at 75°. As a result of this trend, we see that larger bifurcation angles produce greater resistivity and energy loss due to the complicated actions of the blood inside the stent.

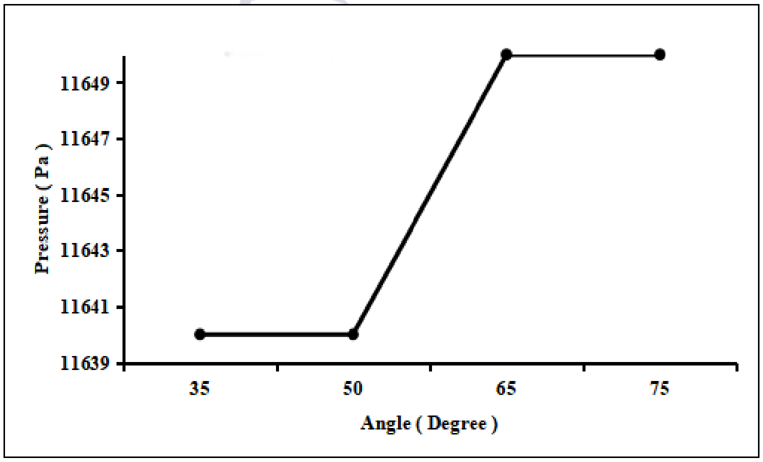


Figure 0.7 Graph between Angles and Pressure

Energy Equation for Wall Shear Stress

The graph presents how wall shear stress (WSS) in different situations is related to energy as part of a bifurcation analysis at angles 35°, 50°, 65° and 75°. The WSS is greatest at 35°, with a value of about 13.5 Pa and there is a notable reduction to 12.9 Pa at 50°, showing weaker energy and shear at that degree. A small increase happens at 65°, then another decrease to 12.75 Pa at 75°. It seems that the larger the angle, the more flow is restricted, and the less energy remains from the shearing action.

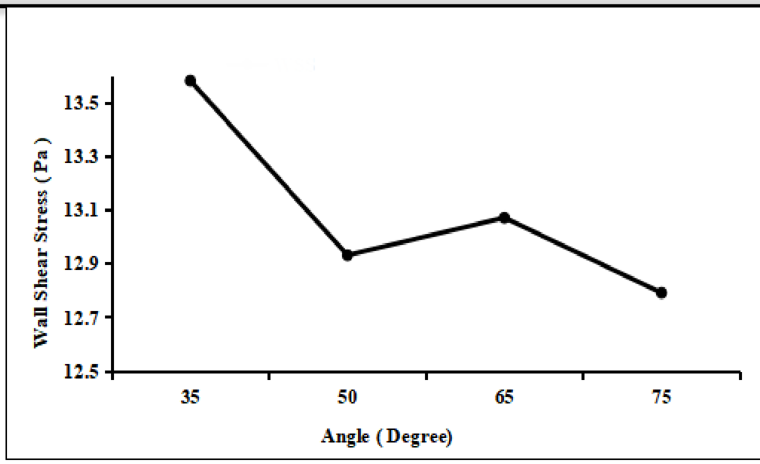


Figure 0.8 Graph between Angle and Wall Shear Stress

Observation for Non-Newtonian Pulsating Blood Flow

The graph shows data for non-Newtonian pulsating blood flow velocity at bifurcation angles of 35°, 50°, 65° and 75°. The velocity is greatest for a pitch of 35° and gets slower until it reaches the lowest value at 75°. It demonstrates that the division of bifurcation geometry has a strong impact on how blood behaves in conditions with pulsing flow. Expanding the angle of the aorta usually disrupts the blood flow more, increasing the body's resistance to blood flow. They explain why arterial geometry is important for hemodynamics and may aid in determining risks for heart diseases in complex vascular areas.

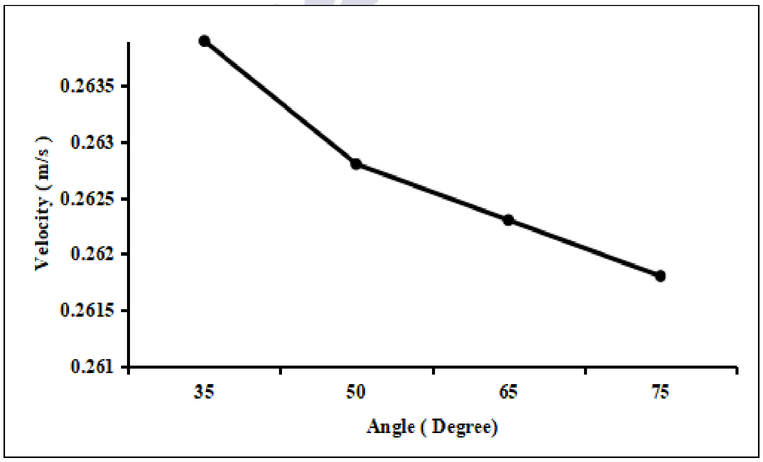


Figure 0.9 Graph between Angles and Velocity

Observation for Wall Shear Stress of Non-Newtonian Pulsating Blood Flow

This graph demonstrates the behaviour of wall shear stress for non-Newtonian pulsating blood flow in bifurcations at angles of 35°, 50°, 65° and 75°. The Work Stress Stressor has its highest value at 35° (~13.93 Pa) and this value sharply drops at 50° (~13.32 Pa). At 65°, the pressure rises slightly, but it falls again at 75° to reach a low of about 13.15 Pa. As the bifurcation angle rises, we observe that flow is more disturbed and the WSS decreases. Wider angles appear to reduce the shear force on vessel walls when the flow is pulsatile and does not maintain straight lines, increasing the chance of vascular issues in these regions.

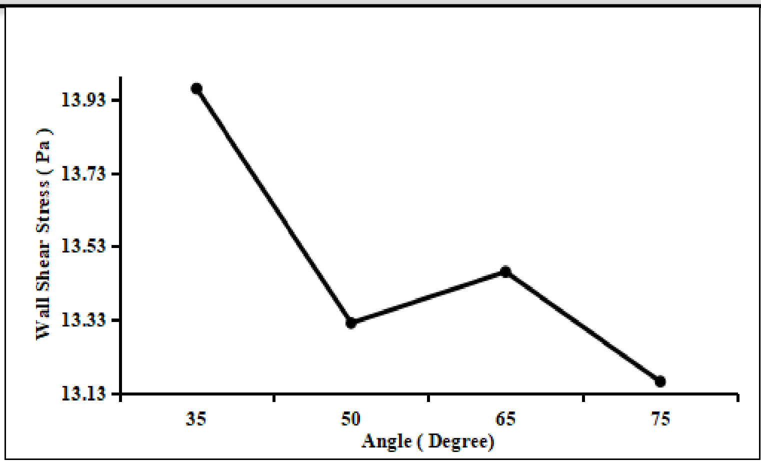


Figure 0.10 Angles vs Wall Shear Stresses

Flow Distribution Between the Angles with Respect to Time

The graph represents the changing pattern of branch flow at bifurcations of 35° and 75° during pulsatile circulation. At this stage (within 0.1 seconds), both setups have a consistent velocity (~0.62 m/s) showing that the inflow is uniform. At this point is where you can see the difference between the angles; the 75° block loses speed much faster and gets close to 0.21 m/s, but the 35° block stays higher at about 0.39 m/s. Because of this, steering with a wider bifurcation creates more difficulty for the wheel to slow down and uses more of the car's energy during this process. After their lowest points, both velocities rise once again, with velocities merging closely to 0.58 m/s at about 0.65 seconds, consistent with a return toward the cycle's top. Generally, the analysis indicates that larger bifurcation angles lead to increased flow disturbance and later recovery which affects how blood is transported efficiently. The results prove that healthy hemodynamics in the arteries depend on proper arterial geometry during natural pulses.

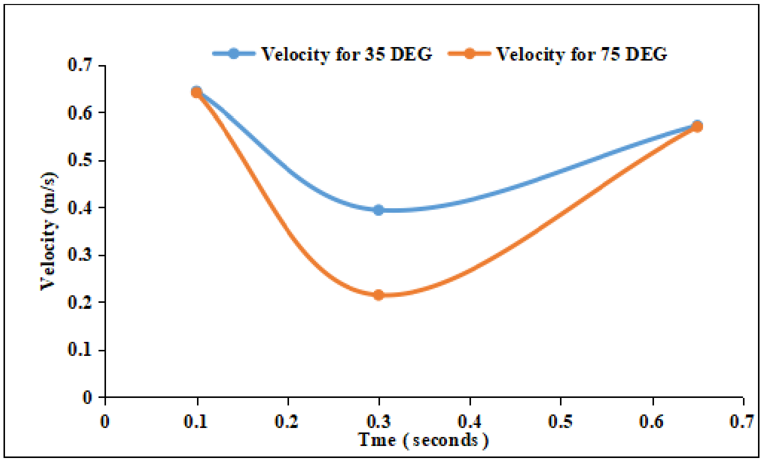


Figure 0.11 Flow distribution between the angles of 35° and 75° with respect to time

Discussions

The study clearly Argentine that the angle between the arteries affects both blood flow and the function seen in arterial bifurcations. A clear trend is noticed in all processes as the angle increases from 35° to 75°: velocity, wall shear stress (WSS) and pressure all change in the same way, showing that flow efficiency falls and resistance rises. Still, Newtonian and energy-based conditions at 35° lead to speedier flow, while larger angles bring unorganized and silent regions of flow commonly found in diseases of the blood vessels. When blood is moving under pulsatile and non-Newtonian conditions, the variation in angle results in bigger decreases in velocity, shorter duration of reduction and more difficulty in overcoming blockage, making it clearer that such blood flows encounter greater resistance. This time series reveals that the flow at 75° bifurcation heals much slower than the flow at 35°, further supporting the idea that wider bifurcation causes harm. According to these patterns, constricted divisions of arteries stabilize blood flow and the health of their walls, but broader branches can disrupt blood movement, lower the strength on the artery wall and significantly increase pressure—situations that favor atherosclerosis and other diseases of the heart. In general, these results suggest that paying attention to artery geometry is important for healthcare decisions and engineering vascular grafts or treatments.

Conclusion

The research examines computational models of artery bifurcations at several angled branches, with angles set at 35°, 50°, 65° and 75°, using the techniques of Computational Fluid Dynamics (CFD). Both regular and irregular models were examined to mimic the behavior of flowing blood through human vessels. It is clear from the simulation that the bifurcation angle changes critically important hemodynamic values such as velocity, pressure patterns and wall shear stress (WSS). Flight with a lower angle of bifurcation (as low as 35°), displayed swift axial velocity, greater wall shear stress and reduced stress differences between pumping and pushing regions, demonstrating a streamlined, effective flow pattern. On the other hand, a bifurcation angle of 75° slowed the flow, increased pressures and expanded areas where WSS was low which is related medically to problems such as poor endothelial function and increased atherosclerotic plaque risk. It was also shown through pulse flow simulations that the delayed recovery of blood velocity and increased flow reversal with a wider-angle point to greater unsteadiness and energy loss. The results of the energy-based and sensitivity analyses agree that, at a resolution of 0.5 mm, the flow calculations are exact and the changes in flow behaviour are small. Overall, the findings stress that bifurcation geometry is a main controller of vascular circulation and that wider angles at bifurcations contribute to abnormal flows and unhealthy flow patterns in arteries. The results help direct how doctors treat patients and how vascular grafts, and endovascular devices are made.

Future Recommendations

In the future, including patient-specific shapes from medical images will help studies better relate to clinical practice. Having fluid-structure interaction (FSI) simulates how the walls change during pulsatile flow. Considering different angles, newer branch sizes and stenosis within the models can reveal more about geometric impacts on blood flow. The use of advanced models for turbulent flows and in checking outcomes with experimental or in vivo data, helps improve the accuracy of the model. Putting these observations into practice for stents and grafts can help create more secure flows and decrease disease risk.

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