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A Comparative Analysis of Stent Performance in Aneurysm: Impact of Newtonian and Non Newtonian Flow Dynamics

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Abstract- *This study conducts a computational fluid dynamics (CFD) analysis to evaluate stent performance in arterial aneurysms, focusing on the impact of Newtonian vs. non-Newtonian blood flow models, and stent design. The parameters which are used for the comparison are: pressure, velocity, wall shear stress and flow diversion. Simulations are done by using ANSYS FLUENT. There are three cases which are considered in this study: (i) Aneurysm without stent (ii) Aneurysm with a regular stent (iii) Aneurysm with a flow-diverter stent. The results show that non-Newtonian modeling yields more clinically realistic outcomes than Newtonian approximations. Because the non-Newtonian models consider the blood shear thinning effect and the viscosity changes in the artery length. The flow-diverter stent outperforms the regular stent, reducing intra-aneurysmal velocity by >99% and WSS by 98.5%, significantly lowering rupture risk. In case of Newtonian models, a regular stent allows the more of the blood to flow into the aneurysm whereas the flow diverter stent reduces more of so that it is more useful than the regular stent. But for the non-Newtonian models, the flow diverter couldn't reduce as much flow like the case of Newtonian models. The non-Newtonian models show a more realistic blood flow simulation. In these cases, patient specific stent designs are needed for the aneurysm treatment. These research contributes to understanding the flow of blood into the artery and aneurysm both for Newtonian and non-Newtonian flow dynamics.*

Keywords: Newtonian, Non-Newtonian, Stent, Shear thinning effect

1. INTRODUCTION

In biomedical engineering, and particularly in vascular research, fluid dynamics is key to understanding blood flow through arteries, especially in cases involving abnormalities such as aneurysms. Blood behaves as a complex fluid, and its flow characteristics can vary significantly depending on whether it is modeled as a Newtonian or Non-Newtonian fluid. This distinction becomes critical when analyzing hemodynamic parameters, such as wall shear stress, velocity distribution, and pressure drop, which are influenced by the properties of blood and the geometry of the vessels. Non-Newtonian fluids can be further categorized into: Shear thinning, Shear thickening, Bingham Plastics, Viscoelastic Fluids [1-2].
Aneurysm is an abnormal condition of a blood vessel. A ruptured aneurysm causes serious damage to human body. It causes bleeding inside the body and causes to death [3-4]. Flow-diverting stents (FDSs) are used in the treatment of arterial aneurysms, especially in complex cases where traditional stent grafts may not be feasible. By reducing flow velocity within the aneurysm sac, FDSs promote thrombosis and vessel remodeling [5]. Wide-neck, fusiform, or complex aneurysms need more complex and unique stent of mechanical and hemodynamic properties. So minimizing complications such as in-stent stenosis or thrombosis, stent technology should be driven in the advanced level [6-7]. Samar et al. explained Newtonian and Non Newtonian flow characteristics in aneurysm. In a Newtonian model, blood is assumed to have a constant viscosity which is independent of the shear rate [8].
Sayemul et al. explained the impact of variation in blood flow velocity in stent performance in terms of its ability to prevent blood flow into aneurysm sac. The regions which has high blood velocity, can exert more force on the stent, potentially leading to stent displacement or deformation. Similarly, areas with low flow velocity may cause thrombus formation, which could block the stent or increase the risk of complications [9].
The regions where blood flow is disrupted, such as at the neck of an aneurysm, pressure increases and flow separation occurs, which contributes to wall stress [10-11]. Aneurysms which has larger neck and higher dome heights, have a higher risk of rupture because of their increased hemodynamic stress and instability within the aneurysm. After the placement of a stent, it alters the flow dynamics within the aneurysm sac, reduces blood flow and promotes thrombosis to prevent rupture [12-13].
So flow diverter stents are used in complex aneurysm treatment such as wide neck aneurysm where traditional coil embolization may not work effectively.

2. GOVERNING EQUATIONS

The conservation of mass for incompressible flow (blood is treated as incompressible):

$$\nabla . v = 0 \text{........................} \ (1)$$

The Navier-Stokes equations govern the motion of fluid flow. For incompressible flow the general form of the Navier-Stokes equation is:

$$P\left(\frac{\partial v}{\partial t} + v.\nabla v\right) = -\nabla p + \mu \nabla^2 v + f \ldots\ldots(2)$$

Wall shear stress (WSS) is a critical parameter in the hemodynamic analysis of aneurysms and stent performance. It is given by:

$$\tau_w = \mu\left(\frac{\partial u}{\partial y}\right)_{y=0} \ldots\ldots\ldots (3)$$

For non-Newtonian fluid model, power law model has been used. The governing equation of power law model is:

$$\mu = K * \dot{\gamma}^{n-1} \ldots\ldots\ldots\ldots\ldots(4)$$

3. NUMERICAL MODELLING

To create the models, two ideal model of aneurysm geometry is created: one is before stent placement and another is after stent placement. Firstly a cylindrical pipe is created which works as the artery model. A sphere is created which has the diameter of 33mm, located at 2mm above the artery. The cylindrical artery is of 4.5mm. The distance from artery inlet to aneurysm proximal is 52 mm and distance from aneurysm to artery outlet is 52mm. Thus, the inlet and outlet are far away from the aneurysm so that the flow characteristics of blood will not be affected by aneurysm. A regular stent has been designed in SOLIDWORKS 2023. Its dimensions are l(0.96mm), m(0.94mm). The stent is of low metal coverage. It is made by meshing of cylindrical wires which is fitted into the parent artery.

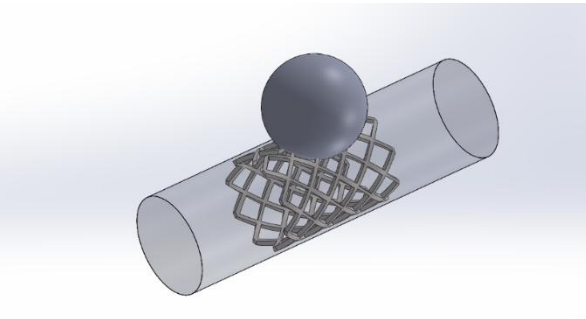


Fig. 1: Placement of Regular Stent in Aneurysm

A flow diverter stent has also be designed in SOLIDWORKS. The flow diverter stent has less porosity than the regular stent. It is more useful for complex shape aneurysm models as it reduces the flow

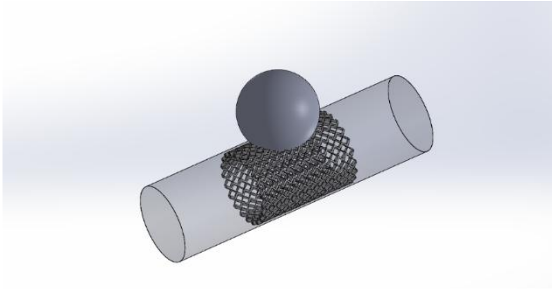


Fig. 2: Placement of Flow Diverter Stent in Aneurysm

blood into aneurysm sac mostly than the regular stent.

In this study, we employed numerical modeling to analyze blood flow behavior and stent performance within an idealized aneurysm geometry. The aneurysm model was designed using SOLIDWORKS, incorporating geometric simplifications to focus on the essential features affecting flow dynamics. This ideal model was then imported into ANSYS for computational fluid dynamics (CFD) simulations.

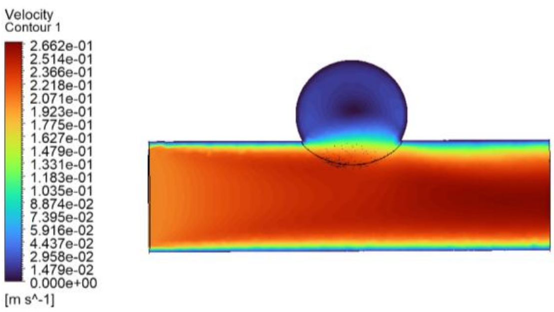
The simulations were conducted for both pre- and post-stent placement conditions to evaluate how the stent alters flow patterns within the aneurysm sac. Two different fluid models were considered: Newtonian and non-Newtonian to account for the shear-thinning behavior of real blood.

4. RESULTS AND DISCUSSION

The results are analyzed for three cases: before placing the stent, after placing the regular and flow diverter stent.

4.1 ANEURYSM WITHOUT STENT

From Fig. 3, we can see that there is enough flow in the aneurysm sac from the artery. The velocity and pressure is enough in the dome. As a result, the risk of aneurysm rupture increases rapidly.



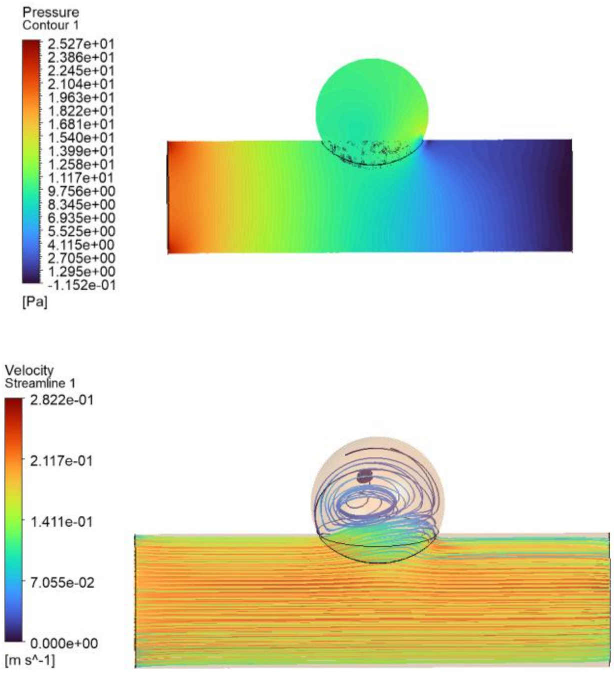
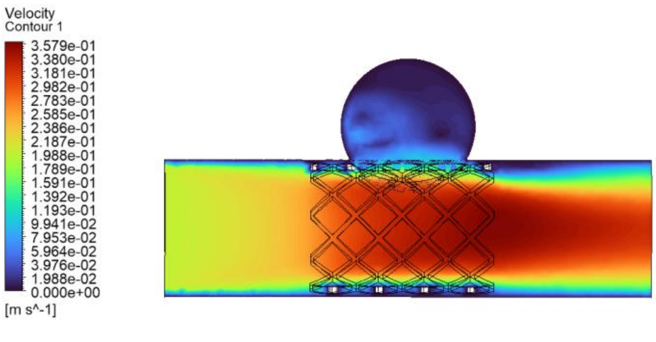
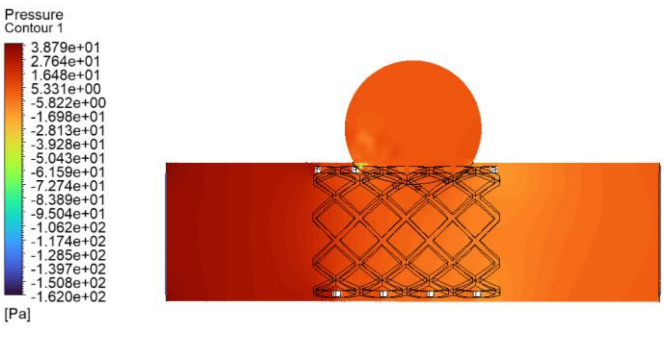


Fig. 3: Velocity Contour, Pressure Contour and Velocity Streamline without stent

4.2 ANEURYSM WITH REGULAR STENT

In Fig. 4, we can see that compared to the unstented case, the pressure contour shows an overall reduction in pressure transmission into the aneurysmal sac**.** The velocity of blood into the aneurysmal portion has also been reduced due to stent placement. The streamline shows that there is a small flow into the aneurysm sac compared to unstented condition but the stent couldn't stop the flow fully which means further modification is needed.





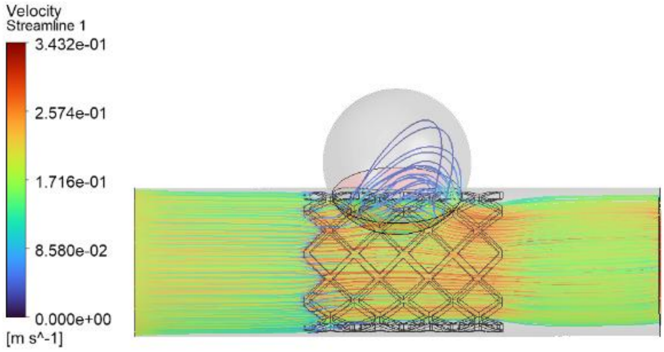
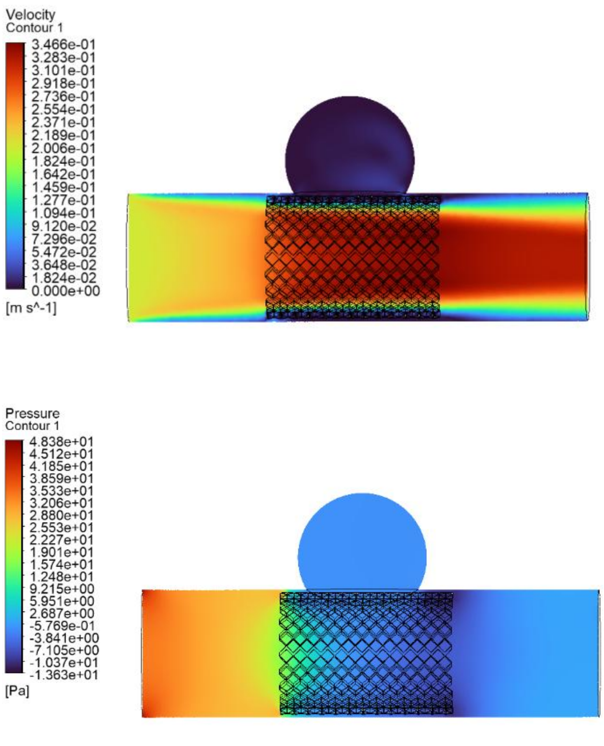


Fig. 4: Velocity Contour, Pressure Contour and Velocity Streamline with Regular Stent

4.3 ANEURYSM WITH FLOW DIVERTER STENT

The flow diverter stent has lesser porosity than the regular stent (typically <70%, metal coverage is 30-35%). It has a high density mesh. The pressure gradient graph shows that there is a gradual decrease in pressure from inlet to outlet. The flow diverter stent effectively moderates pressure drop by diverting the flow from the aneurysm sac. The velocity contour shows that the velocity magnitude is lower and more uniform compared to the case of regular stent. The streamlines pass smoothly through the main artery but do not significantly enter the aneurysm sac, indicating successful flow diversion. The streamline shows that direct jet entry into the aneurysm is blocked. This indicates that the flow diverter stent is more effective than the regular stent in reducing the blood flow into the aneurysm sac.



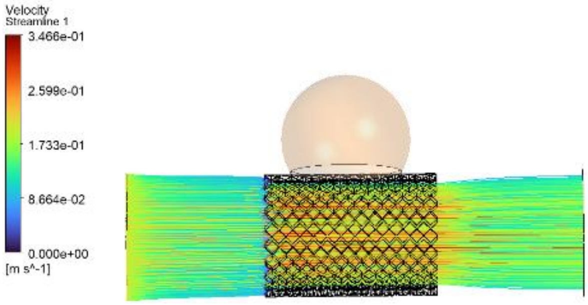


Fig. 5: Velocity Contour, Pressure Contour and Velocity Streamline with Flow Diverter Stent

Here, the flow diverter is useful for Newtonian fluid. But in case of Non Newtonian fluid, it will act differently.

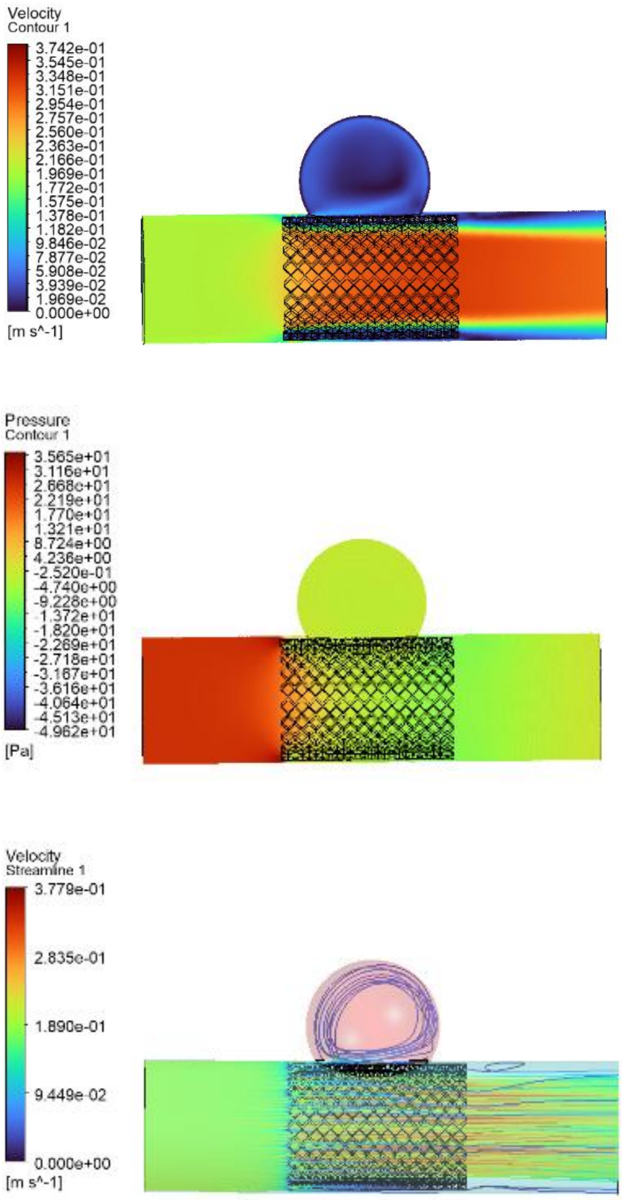


Fig. 6: Velocity Contour, Pressure Contour and Velocity Streamline with Flow Diverter Stent using Non-Newtonian Fluid

In case of Non-Newtonian fluid, the pressure contour shows that there is a high pressure at inlet of artery. The pressure is high at the dome compared to the Newtonian condition. The velocity contour shows a higher velocity at artery and dome. The velocity streamline shows that there is enough flow into the aneurysm sac.

The streamline is not smooth like the Newtonian condition. It is because the Non-Newtonian fluid has shear thinning effect. It causes the blood to change its viscosity with time. As a result, the velocity of blood also changes with time. It shows a vortex formation in the dome. So the pressure and velocity have been increased compared to the Newtonian condition. Blood actually behaves like a Non-Newtonian fluid. This simulation indicates that the flow diverter stent with less porosity is effective for Newtonian fluid but is not much effective for Non-Newtonian fluid. So further modification is needed for the stent for Non-Newtonian condition.

4.4 TURNOVER TIME AND WSS RESULT

The turnover time is a critical parameter that calculates the time required for the blood volume within the aneurysm to be completely replaced by incoming flow.

$$tt = \frac{V\ (aneurysm\ )}{\theta\ (inflow)}$$

Table 1: Turnover time [12]

Configuration	Turnover Time	Reference Study
Untreated Aneurysm	1.0142	2.1
With Regular Stent	1.8091	3.8
With Flow Diverter Stent	3.5253	6.8

Turnover time gives insights into how effectively a stent diverts or blocks blood from flowing into the aneurysm sac. The untreated aneurysm turnover time value indicates natural blood flow dynamics and wall shear stress without any intervention. The turnover time increases in the case of using regular stent indicating that the regular stent affects blood flow dynamics by reducing turbulence and altering shear stresses in the aneurysmal sac. It improves blood flow characteristics by preventing expansion of the aneurysm, but the effect is less pronounced compared to the flow diverter stent. The flow diverter stent has the most pronounced effect on the blood flow, with the longest turnover time, which may indicate a significant reduction in blood turbulence and more effective long-term remodeling of the aneurysm.

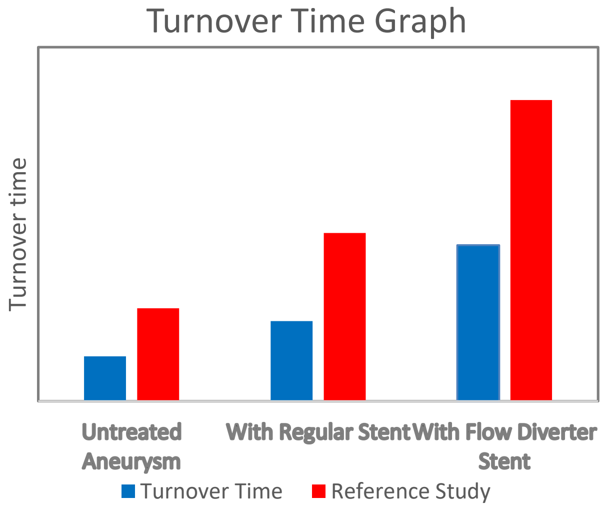


Fig. 7: Validation chart for turnover time

Table 2: Wall Shear Stress [12]

Configuration	WSS Result	Reference Study	Difference
Without Stent	1.58669	1.620	2.05% lower
With Regular Stent	1.049928	0.880	19.3 higher
With Flow Diverter Stent	0.12309933	0.240	48.4% lower

From the table 5.1, we can see that WSS result without stent closely aligns with the reference value which suggests that the numerical setup, boundary conditions

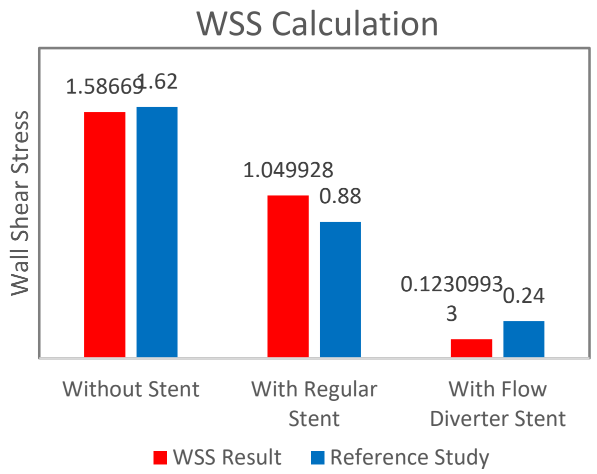


Fig. 8: Wall Shear Stress Chart

are perfectly done. The WSS result with regular stent is slightly higher than the reference value which is still acceptable (< 20%) which could arise from different stent wire geometry or spatial averaging techniques. But WSS with flow diverter stent result is significantly lower than the reference value. It means there might be denser flow diverter mesh.

5. CONCLUSION

Aneurysms are abnormal bulges in arteries, and stent placement is a widely used treatment to reduce blood flow into the aneurysm sac, lowering rupture risk. Computational Fluid Dynamics (CFD) enables detailed analysis of blood flow through stents, assessing their effectiveness. This study compares Newtonian and non-Newtonian models, with the latter capturing blood's shear-thinning behavior for more accurate hemodynamic predictions. Two stent designs were evaluated: a regular stent and a flow-diverter stent, the latter having lower porosity and greater efficacy in reducing aneurysm inflow and wall shear stress (WSS). Results align with clinical data, showing significant WSS reduction with flow-diverter stents. Non-Newtonian simulations reveal critical flow conditions not seen in Newtonian models, highlighting the need for patient-specific stent designs in complex aneurysm geometries. Future research should focus on optimizing stent design for such cases, ensuring flexibility, biocompatibility, and tailored flow control.

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