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Effects of Acetylsalicylic Acid on Blood Flow Through an Artery under Atherosclerotic Condition

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Abstract: Acetylsalicylic acid is a salicylate drug which is used to decrease viscosity of blood by diluting the blood which ultimately decreases the blood pressure of the patients. The effects of peripheral layer on blood flow characteristics due to the presence of a mild stenosis are also studied in this study. A two Fluid Model for blood flow through abnormally constricted stenosed artery has been developed. The model consists of a core region of suspension of all erythrocytes assumed to be Bingham Plastic Fluid Model, to find the effects of peripheral-layer viscosity and a peripheral plasma layer free from cells of any kind of Newtonian fluid is considered. It is shown that the magnitudes of the flow characteristics significantly increase with stenosis shape parameter and the peripheral layer causes marked reduction in the magnitudes of the flow characteristics. Physiological relevance and the influence of various parameters are discussed.

Key words: Peripheral layer, Bingham Plastic Fluid Model, apparent viscosity, stenosed artery, Newtonian fluid, atherosclerosis, resistance to blood flow

INTRODUCTION

Acetylsalicylic acid has an antiplatelet effect by inhibiting the production of thromboxane which under normal circumstances binds platelet molecules together to create a patch over damaged walls of blood vessels. Because the platelet patch can become too large and also block blood flow, locally and downstream, aspirin is also used long-term at low doses, to help prevent heart attacks, strokes and blood clot formation in people at high risk for developing blood clots (Murata, 1998). It has also been established that low doses may be given immediately after a heart attack to reduce the risk of another heart attack or of the death of cardiac tissue (Pralhad and Schultz, 2004; Sanyal *et al*., 2007). Acetylsalicylic acid is a salicylate drug, often used as an analgesic to relieve minor aches and pains as an antipyretic to reduce fever and as an anti-inflammatory medication. Salicylic acid, the main metabolite of aspirin, is an integral part of human and animal metabolism. While much of it is attributable to diet, a substantial part is synthesized endogenously (Mishra and Verma, 2010). The coronary arteries supply blood to the heart. Aspirin is recommended for 1-6 months after placement of stents in the coronary arteries and for years after a coronary artery bypass graft. The carotid arteries supply blood to the brain. Patients with mild carotid artery stenosis benefit from aspirin; it is recommended after a carotid endarterectomy or carotid artery stent. After vascular surgery of the lower legs using artificial grafts which are sutured to the arteries to improve blood supply this acid is used to keep the grafts open. The intimal thickening of stenotic artery was understood as an early process in the beginning of atherosclerosis. Atheros-clerosis (Fig. 1) is a leading cause of death in many countries. There is considerable evidence that vascular fluid dynamics plays an important role in development and progression of arterial stenosis which is one of the most widespread diseases in human beings.

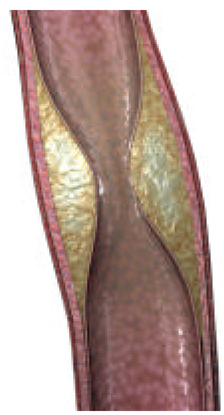

Fig. 1: Atherosclerosis

Blood consists of a suspension of cells in an aqueous solution called plasma which is composed of about 90% of water and 7% protein. There are about 5×10^9 cells in a mililiter of healthy human blood of which about

95% are red cells or erythrocytes whose main function is to transport oxygen from the lungs to all the cells of the body and the removal of carbon dioxide formed by metabolic processes in the body to the lungs. About 45% of the blood volume in an average man is occupied by red cells. This fraction is known as hematocrit. Of the remaining white cells or leucocytes constitute about 1-6th or 1% of the total these play a role in the resistance of the body to infection; platelets from 5% of total and they perform a function related to blood clotting. The experimental results by several mathematicians (Jung *et al*., 2004; Krumholz *et al*., 1995; Paterson *et al*., 2008; Rathod and Tanveer, 2009; Shukla *et al*., 1980) have been proposed to study the various aspect of blood flow through stenosed condition. To explain the observed Fahraeus-Lindquist effect, (Lerche, 2009) has considered a two-fluid model with both fluids as Newtonian fluids and with different viscosities, i.e., the peripheral layer with the viscosity of plasma and the core with the viscosity equivalent to shear viscosity of blood.

Chakravarty and Mandal (2001), Haldar (1985) and Lee (1990) have assumed that either both layers, i.e., peripheral layer of plasma and core region are of Newtonian fluid or both layers are of non-Newtonian fluids. This seems to be improper because it has been shown experimentally by Pontrelli (2001) Sankar and Hemalatha (2006) and Shalmana *et al*. (2002) that plasma is a Newtonian fluid and core region fluid behaves like a non-Newtonian fluid. It have been proposed by Secomb and El-Kareh (1994) and Shukla *et al*. (1980) that blood flow through an artery in smaller diameter consists of peripheral plasma layer which being cell-free is Newtonian in character and a core of red cell suspension in plasma. The effects of stenosis are much more important in microcirculation where peripheral layer thickness and viscosity effects dominate the flow characteristics. It have also been investigated by the Shukla *et al*. (1980) and Singh *et al*. (2010) that the effects of this peripheral layer in microcirculation and found that the viscosity of the peripheral layer fluid is 2-3 times higher in the diabetic patients these subjects are more prone to such diseases.

MATERIALS AND METHODS

Consider the axisymmetric flow of blood in a uniform circular tube with an axially non-symmetric but radially symmetric mild stenosis. The geometry of the stenosis as shown in Fig. 2 is assumed to be manifested as:

$$\frac{R(z)}{R_0} = 1-A\left[L_0^{(m-1)}(z-d)-(z-d)^m\right], \quad d \le z \le d+L_0 \qquad (1)$$

$$=1, \quad \text{otherwise}$$

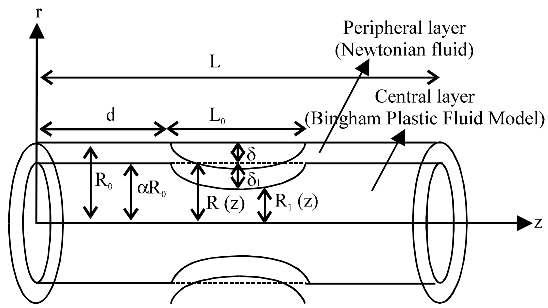

Fig. 2: Geometry of stenosed artery with peripheral layer

Where:

$R(z)$ and R_0 = The radius of the capillary with and without stenosis, respectively
L_0 = The stenosis length
d = Location
$m \ge 2$ = A parameter determining the stenosis shape and is referred to as shape parameter

Axially symmetric stenosis occurs when m = 2 and a parameter A is given by:

$$A = \frac{\delta}{R_0 L_0^m}\frac{m^{m/(m-1)}}{(m-1)}$$

where, δ denotes the maximum height of stenosis at $z = d+L_0/m^{1/(m-1)}$. $\delta/R_0 << 1$. The function $R_1(z)$ representing the shape of the central layer assumed as:

$$\frac{R_1(z)}{R_0} = \alpha - A_1\left[L_0^{(m-1)}(z-d)-(z-d)^m\right], \quad d \le z \le d+L_0$$

$$= \alpha \quad \text{otherwise} \qquad (2)$$

$$A_1 = \frac{\delta_1}{R_0 L_0^m}\frac{m^{m/(m-1)}}{(m-1)}$$

where, δ_1 denotes the maximum bulging of interface at $z = d+L_0/m^{1/(m-1)}$ due to the presence of stenosis and α is the ratio of the central core radius to the tube radius in the unobstructed region.

Conservation equation and boundary condition: The equation of motion for laminar and incompressible, steady, fully developed, one-dimensional flow of blood whose viscosity varies along the radial direction in a capillary is:

$$\left(-\frac{dP}{dz}\right)+\frac{1}{r}\frac{\partial}{\partial r}\left[r\mu\left(\frac{\partial u}{\partial r}\right)\right]=0 \qquad (3)$$

where (z, r) are (axial, radial) co-ordinates with z measured along the axis and r measured normal to the axis of the capillary. Following boundary conditions are introduced to solve the equations:

$$\begin{aligned} &\frac{\partial u}{\partial r} = 0 \quad \text{at } r = 0,\ u = 0 \quad \text{at } \ r = R(z) \\ &P = P_0 \quad \text{at } z = 0,\ P = P_L \ \text{at } \ z = L \\ &\tau \text{ is finite} \qquad \text{at } r = 0 \end{aligned} \tag{4}$$

To see the effect of peripheral layer viscosity on the stenosis shape parameter, resistance to flow, shear stress and apparent viscosity, we consider the viscosity function as follows:

$$\begin{aligned} &\mu = \mu_1, \quad 0 \le r \le R_1(z) \\ &\mu = \mu_2, \quad R_1(z) \le r \le R(z) \end{aligned} \tag{5}$$

where, μ_1 and μ_2 are the viscosities of the central and the peripheral layers, respectively.

Bingham Plastic Fluid Model: For Bingham Plastic fluid, the stress-strain relation is given by:

$$\tau = \tau_0 + \mu\left(-\frac{du}{dr}\right) \tag{6}$$

Where:

τ	=	$[-dp/dz\ (r/2)]$
τ_0	=	$[-dp/dz\ (R_P/2)]$
u	=	Axial velocity
μ	=	Viscosity of fluid
-dp/dz	=	Pressure gradient

Solution of the problem: The flow flux Q at any cross section is defined as:

$$Q = \int_0^{R(z)} 2\pi r u\, du = \int_0^{R(z)} \pi r^2 \left(-\frac{du}{dr}\right) dr \tag{7}$$

on using Eq. 3, 6 and boundary condition 4 we get;

$$Q_1 = \int_0^{R_1(z)} \pi r^2 \left(-\frac{du}{dr}\right) dr = \frac{\pi P R_1^2(z)}{8\mu_1} \tag{8}$$

$$Q_2 = \int_{R_1(z)}^{R(z)} \pi r^2 \left(-\frac{du}{dr}\right) dr = \frac{\pi P}{8\mu_2}\left[R^2(z) - R_1^2(z)\right] \tag{9}$$

the total flux, Q is;

$$Q = Q_1 + Q_2$$

and Q is written as;

$$Q = \frac{\pi P}{8\mu_2}\left[R^2(z) - (1-\pi)R_1^2(z)\right] \tag{10}$$

$$\mu = \frac{\mu_2}{\mu_1}$$

from Eq. 10 the pressure gradient is written as follows:

$$P = \frac{8\mu_2 Q}{\pi\left[R^2(z) - (1-\mu)R_1^2(z)\right]} \tag{11}$$

To determine λ, we integrate Eq. 11 for the pressure P_L and P_0 which are the pressures at z = 0 and z = L, respectively where, L is the length of the tube. The resistance to flow is defined as follows:

$$\lambda_0 = \frac{P_L - P_0}{Q} \tag{12}$$

Let λ_N is the resistance to flow for Newtonian fluid with no stenosis then:

$$\lambda_N = \frac{8\mu_1 L}{\pi R_0^4} \tag{13}$$

from Eq. 12 and 13;

$$\lambda = \lambda_0/\lambda_N = 1 - (L_0/L) + \left(\left(1-(1-\mu)\alpha^2\right)/L\right) \int_d^{d+L_0} dz / \left(R(z)/R_0\right)^2 - (1-\mu)\left(R_1(z)/R_0\right)^2\Big) \tag{14}$$

Equation 12 can be rewritten as:

$$Q = \frac{\pi P R^4}{8\mu_{app}}$$

where, μ_{app} is the apparent total tube flow viscosity given by:

$$\mu_{app} = \frac{\mu}{1-(1-\mu)\alpha^4}\frac{1}{\left(R(z)/R_0\right)^2} \tag{15}$$

The shearing stress at the maximum height of the stenosis can be written as:

$$\tau_S = 4\mu_2 Q\left(1 - \frac{\delta}{R_0}\right)/\pi R_0^2\left[\left(1 - \frac{\delta}{R_0}\right)^2 - (1-\mu)\left(\alpha - \frac{\delta}{R_0}\right)^2\right] \tag{16}$$

and the shear stress for Newtonian fluid with no stenosis is as:

$$\tau_N = \frac{4\mu_1 Q}{\pi R_0^2} \tag{17}$$

now the ratio of shearing stresses at the wall can be written as:

$$\tau = \frac{\tau_S}{\tau_N} = \frac{\mu}{\left[1-(1-\mu)\alpha^2\left(1-\frac{\delta}{R_0}\right)^2\right]} \tag{18}$$

RESULTS AND DISCUSSION

The model presented above contributes to the fact that blood possesses an inbuilt mechanics of reducing drag due to the presence of peripheral layer. Therefore, incorporation of a cell free layer of plasma and a central core of thickly concentrated suspension of cells with higher viscosity ($\mu_2 > \mu_1$) describes the simplest representation of blood in small diameter vessels. The results obtained in this study consist of the expression for resistance to flow (λ) in Eq. 14, expression for apparent viscosity (μ_{app}) in Eq. 15 and expression for shear stress in Eq. 18 and displayed graphically. Figure 3 and 4 show the variation of resistance to flow with stenosis size, stenosis length, stenosis shape parameter and peripheral layer viscosity. It is observed from the figures that the resistance to flow decreases as stenosis shape parameter increases while it increases as stenosis size and peripheral layer viscosity increases. A slight change in the stenosis size (radius of the artery) brings about a noticeable change in the resistance to flow (Singh and Rathee, 2010). It is found by Tandon and Rana (1995) and Venkateshwarlu and Anand (2004) that the peripheral layer viscosity of blood in diabetic patients is higher than in non-diabetic patients, resulting higher resistance to blood flow. Thus, diabetic patients with higher peripheral layer viscosity are more prone to high blood pressure. Therefore, the resistance to blood flow in case of diabetic patients may be reduced by reducing viscosity of the plasma. This can be done by injecting saline water to such patients the process is called dilution in medical terms. Figure 5 and 6 consist the results for wall shear stress for different values of stenosis size and stenosis length, stenosis shape parameter and peripheral layer viscosity. It is observed from the figures that the wall shear stress decreases as stenosis shape parameter increases but in the case of increasing stenosis size, stenosis length and peripheral layer viscosity wall shear stress is increasing. Figure 7 and 8 highlighted the results for apparent viscosity with the variation of stenosis size, stenosis length, stenosis shape parameter and peripheral layer viscosity. These figures depict that apparent viscosity increases as stenosis size, stenosis length and peripheral

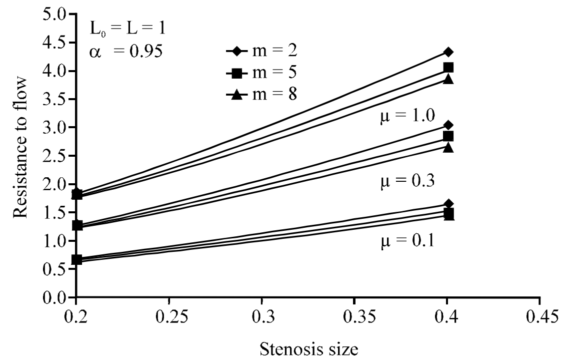

Fig. 3: Variation of resistance to flow with stenosis size for different values of stenosis shape parameter

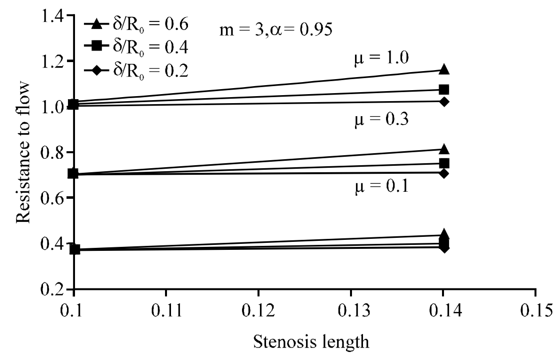

Fig. 4: Variation of resistance to flow with stenosis length for different values of stenosis size

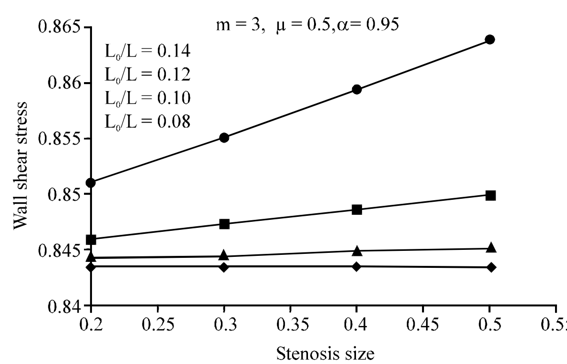

Fig. 5: Variation of wall shear stress with stenosis size for different values of stenosis length

layer viscosity increases. It has also been seen from the graphs that the apparent viscosity decreases as shape parameter increases. These results are qualitative agreement with the observation of Sanyal *et al.* (2007) and Shukla *et al.* (1980). In normal human artery, apparent viscosity is found to decrease with the artery radius and is called Fahraeus-Lindquist effect. One may conclude that peripheral layer viscosity plays an important role in lowering the resistance to flow and wall shear stress along

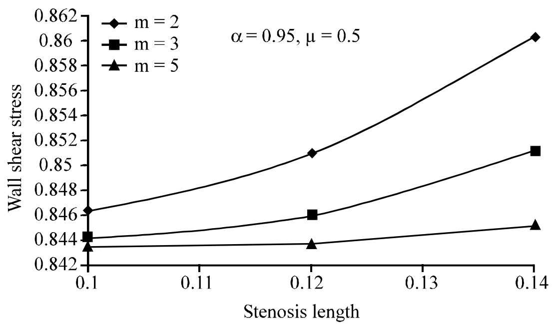

Fig. 6: Variation of wall shear stress with stenosis length for different values of stenosis shape parameter

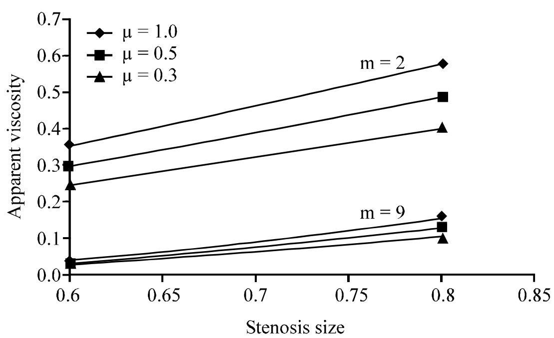

Fig. 7: Variation of apparent viscosity with stenosis size different values of peripheral layer viscosity

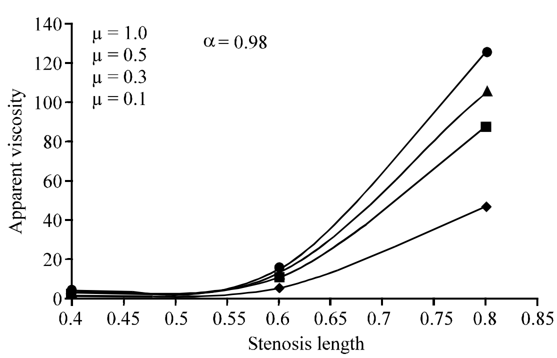

Fig. 8: Variation of apparent viscosity with stenosis length for values of peripheral layer viscosity

the increasing stenosis thickness. In medical practice several medicines are prescribed to lower the plasma viscosity and by injecting saline water intra-venously (Singh *et al*., 2010).

CONCLUSION

The effect of peripheral layer viscosity on the blood flow in the presence of mild stenosis in the lumen of the artery has been investigated by using Bingham Plastic Fluid Model. It has concluded that the resistance to flow, apparent viscosity and wall shear stress have been found to increases with viscosity of peripheral layer but the same are not found to increase as the shape of stenosis increases. The model predicts increase in wall shear stress with peripheral layer viscosity. Predicted trends are found to exist in artery and hence validate the model. More experimental results are required for further development from clinical point of view.

REFERENCES

Chakravarty, S., P.K. Mandal, 2001. Two-dimensional blood flow through tapered arteries under stenotic conditions. Int. J. Non-linear Mech., 36: 731-741.

Haldar, K., 1985. Effects of the shape of stenosis on the resistance to blood flow through an artery. Bull. Mathe. Biol., 47: 545-550.

Jung, H., J.W. Choil and C.G. Park, 2004. Asymmetric flows of non-Newtonian fluids in symmetric stenosis artey. Korean Aus. Rheol. J., 16: 101-108.

Krumholz, H.M., M.J. Radford, E.F. Ellerbeck, J. Hennen and T.P. Meehan, 1995. Aspirin in the treatment of acute myocardial infarction in elderly *Medicare beneficiaries*: Patterns of use and outcomes. Circulation, 92: 2841-2847.

Lee, T.S., 1990. Numerical studies of fluid flow through tubes with double constrictions. I. J. Numer. Methods Fluids, 11: 1113-1126.

Lerche, D., 2009. Modeling Hemodynamics in Small Tubes (Hollow Fibers) Considering Non-Newtonian Blood Properties and Radial Hematocrit Distribution. In: Biomechanical Transport Processes, Mosora, F. (Eds.). New York, ISBN: 9780306436765, Plenum, pp: 243-250.

Mishra, B.K. and N. Verma, 2010. Effect of stenosis on non-Newtonian flow of blood in blood vessels. Aust. J. Basic Applied Sci., 4: 588-601.

Murata, T., 1998. Theoretical analysis of flow properties of aggregating red cell suspensions in narrow horizontal tubes. Clini. Hemorh., 14: 519-530.

Paterson, J.R., G. Baxter, J.S. Dreyer, J.M. Halket, R, Flynn and J.R. Lawrence, 2008. Salicylic acid sans aspirin in animals and man: Persistence in fasting and biosynthesis from benzoic acid. J. Agric. Food Chem., 56: 11648-11652.

Pontrelli, G., 2001. Blood flow through an axisymmetric stenosis. Proc. Inst. Mech. Eng. H, 215: 1-10.

Pralhad, R.N. and D.H. Schultz, 2004. Modeling of arterial stenosis and its applications to blood diseases. Math. Biosci., 190: 203-220.

Rathod, V.P. and S. Tanveer, 2009. Pulsatile flow of couple stress fluid through a porous medium with periodic body acceleration and magnetic field. Bull. Malays. Math. Sci. Soc., 32: 245-259.

Sankar, D.S. and K. Hemalatha, 2006. Pulsatile flow of herschel-bulkey fluid through stenosed arteries: A mathematical model. Int. J. Non-Liner Mech., 41: 979-990.

Sanyal, D.C., K. Das and S. Debnath, 2007. Effect of magnetic field on pulsatile blood flow through an inclined circular tube with periodic body acceleration. J. Phys. Sci., 11: 43-56.

Secomb, T.W. and A.W. El-Kareh, 1994. A model for motion and sedimentation of cylindrical red cell aggregation during slow blood flow in narrow tubes. Biomech. Eng., 116: 243-249.

Shalman, E., M. Rosenfeld, E. Dgany and S. Einav, 2002. Numerical modeling of the flow in stenosed coronary artery: The relationship between main hemodynamic parameters. Comput. Biol. Med., 32: 329-344.

Shukla, J.B., R.S. Parihar and B.R.P. Rao, 1980. Effects of stenosis on non-Newtonian flow of blood in an artery. Bull. Math. Biol., 42: 283-294.

Singh, B., P. Joshi and B.K. Joshi, 2010. Blood flow through an artery having radially non-symmetric mild stenosis. Applied Math. Sci., 4: 1065-1072.

Singh, J. and R. Rathee, 2010. Analytical solution of two-dimensional model of blood flow with variable viscosity through an indented artery. Int. J. Phys. Sci., 5: 857-1868.

Tandon, P.N. and U.V.S. Rana, 1995. A new model for blood flow through an artery with axisymmetric stenosis. I. J. Biomed. Comput., 38: 257-267.

Venkateshwarlu, K.R. and J. Anand, 2004. Numerical solution of unsteadyblood flow through an indented tube with atherosclerosis. Indian J.Biochem. Biophys., 41: 241-245.