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Influence of Magnetic Field on blood flow through Stenosed Artery using Casson's Fluid Model

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ABSTRACT:
The present investigation of atherosclerotic arteries deals with mathematical models that represent behavior of blood flow through an axially non-symmetric but radially symmetric stenosed artery in the presence of magnetic field. Here, the rheology of the flowing blood is characterised by a generalized Casson's fluid model. The effect of magnetic field is considered in the transverse direction of blood flow and viscosity of blood is taken as radial co-ordinate dependent. An extensive quantitative analysis has been performed based on numerical computations in order to estimate the effects of Hartmann number, flow behavior index, generalised Reynolds number, severity of the stenosis on various parameters such as flow velocity, stenosis shape and wall shear stress by means of their graphical representations so as to validate the applicability of the proposed mathematical model. It is observed that the magnitudes of the blood flow characteristics significantly increase with in the red cell concentration, which is depending on hematocrit value of blood. The importance of the decreasing velocity and resistance with increasing Hartmann numbers is also pointed out in the results.

Key words: Resistance to flow, Shape of stenosis, Magnetic field, Wall shear stress, Viscosity of blood, Casson's fluid model.

INTRODUCTION

Atherosclerosis is the leading cause of morbidity and mortality. It is a progressive diseasese characterized by localized plaques that form within the artery wall. As the disease progresses, these plaques enlarge and either directly or indirectly, lead to impairment of blood flow. This in turn can have serious consequences, such as blockage of the coronary arteries and carotid arteries.

Artherosclerotic lesions are found preferentially at specific sites in the arterial system, typically near bends, bifurcations, and other reasons characterized by complex blood flow patterns. These observations, as well as data about the response of endothelial cells to mechanical forces, suggest that the hemodynamic, i.e. fluid dynamic related phenomena play a role in the initiation and progression of the atherosclerosis. It is well known that the external magnetic field has considerable effect on the biological system of human.

The magnetic behaviour of blood is justified due to the haemoglobin molecule, a form of ironoxides, which is present at a uniquely high concentration in the mature red blood cells [1]. It is found that the blood possess the property of diamagnetic material when oxygenated and paramagnetic when deoxygenated. In an arterial constriction blood viscosity increases due to the conservation of mass, producing increased wall shear stress in the region of the blood acceleration. Several attempts have been made in the literature to study the effect of stenosis on the blood flow characteristics, including the important contribution of Young [2], Nerem [3], Haldar [4], Bitoun and Bellet [5]. Chakravarty [6], Srivastava and Saxena [7], Srivastava [8] have studied the effect of stenosis on the resistance to flow through artery by considering the behaviour of blood as a Casson's fluid model. The response of blood flow through an artery under stenotic conditions has been attempted by Srivastava [9] and Shukla et al., [10]. But the problem of flow under magnetic effects becomes much more difficult through arery with stenosis at some region and very few researchers have attempted the flow problem under magnetic effects.

A little attention have been made by Tandon and Pal [11], Sud et al., [12] and Mazumdar et al., [13] to study the effect of magnetic field on physiological fluid flows. It has been found that with the help of magnets, the flow of blood in arteries is properly regulated with the regulation in flow. It has also been reported by Barnothy [14] that the biological systems are affected by magnetic field. Sud and Sekhon [15] and Tzitzilakis [16] have analysed the effect of magnetic on blood flow through the human arterial system. Amos and Ogulu [17] concluded a similar study in which they obtained numerical results for the stream function and vorticty using the Gelarkin technique of the finite element method. The effect of an externally applied magnetic field over the flow characteristics of blood in a single stenosed artery has been analyzed by Haldar [18].

Computational modeling of flow in diseased arteries using realistic geometries derived from magnetic resonance imaging is gaining favour as a tool for understanding and predicting cardiovascular disease Secomb [19] and Vittorio et al., [20]. This is because in vivo measurements of the flow field in an artery can be costly and are only possible for arteries that are easily accessible. The published literature on the stenosis further reveals that very few studies are concerned with the problem of symmetric stenosis. In an actual situation, however, the increase in the arterial wall thickness would not be symmetrical. To generalize the problem further, an attempt is therefore made in the present investigation. In this study a mathematical model is proposed to describe blood flow through an axially non-symmetric but radially symmetric stenosed artery when blood is represented as Casson's fluid and a uniform magnetic field is applied on the flow.

FORMULATION OF THE PROBLEM

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 wall surface can be described as, [Fig.1],

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

where $R'(z)$ is the radius of the artery with stenosis, R_0 is the constant radius of the artery. L_0 is the stenosis length and d indicates the stenosis location, and $m \geq 2$ is a parameter determining the stenosis shape and is referred to as stenosis shape parameter. Here axially symmetric stenosis occurs when m = 2, the parameter A is given by:

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

where δs denotes the maximum height of stenosis at $z' = d' + L_0' / m^{1/(m-1)}$. The ratio of the stenosis height to the radius of the normal artery is much less than unity.

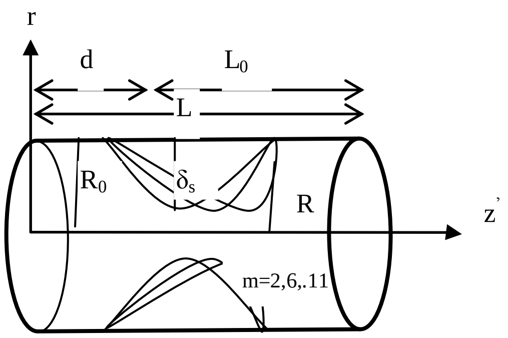

Fig. (1): Geometry of Stenosis

Casson's fluid model:

The Casson's relation is commonly written as;

$$\tau'^{1/2} = \tau_0'^{1/2} + \mu'^{1/2}\left(-\frac{du'}{dr'}\right)^{1/2}, \qquad \text{if } \tau' \ge \tau'_0, \qquad (2)$$

$$\frac{du'}{dr'} = 0 \qquad \text{if } \tau' < '\tau_0$$

where $\tau'_0 = -\frac{dp'}{dz'}\frac{R'_c}{2}$

and R_c is the radius of the plug-flow region, τ_0 is yield stress, τ is shear stress and μ denotes Casson's viscosity coefficient.

Governing equations

Governing equation can be written as:

$$\left(-\frac{\partial P'}{\partial Z'}\right) + \frac{1}{r'}\frac{\partial}{\partial r'}\left(\mu' r' \frac{\partial u'}{\partial r'}\right) + \left(J' \times B'\right) = 0 \qquad (3)$$

$$J' = \sigma(E' + u' \times B') \text{ and } \mu' = \mu_0 \left(\frac{r'}{R_0}\right)^{(-M)} \qquad (4)$$

Where E' is electric field, B' is magnetic field, σ is electric conductivity, J' is magnetic flux and M is a parameter depending upon the hematocrit value.

Boundary conditions

Following boundary conditions are introduced to solve the above equations:

$$\left(\frac{\partial u'}{\partial r'}\right) = 0 \quad \text{at} \quad r' = 0 \qquad (5)$$
$$u' = 0 \quad \text{at} \quad r' = R(z)$$

Non dimensional scheme

$$R = \left(\frac{R'}{R_0}\right), \mu = \left(\frac{\mu'}{\mu_0}\right), r = \left(\frac{r'}{R_0}\right), L_0 = \left(\frac{L_0'}{L}\right), \sigma = \left(\frac{\sigma'}{R_0}\right), \qquad (6)$$

$$Re = \left(\frac{\rho U_0 R_0}{\mu_0}\right), d = \left(\frac{d'}{L}\right), z = \left(\frac{z'}{L}\right), P = \left(\frac{P'}{\rho U_0^2}\right), u = \left(\frac{u'}{U_0}\right)$$

The governing equations and boundary conditions are transformed to:

$$R(z) = 1 - A[L_0^{(m-1)}(z-d) - (z-d)^m], \quad d \le z \le d + L_0 \qquad (7)$$
$$=1, \quad \text{otherwise,}$$

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

$$r^{-M}\left(\frac{\partial^2 u}{\partial r^2}\right) + (1-M)\, r^{-(1+M)}\left(\frac{\partial u}{\partial r}\right) - H^2 u = Re\, \varepsilon \left(\frac{\partial p}{\partial z}\right) \qquad (8)$$

Where, $J = \sigma(E + u \times B)$, $\mu = r^{-M}$, and $H^2 = \left(\frac{B_0^2 R_0^2 \sigma}{\mu_0}\right)$

$$\tau^{1/2} = \tau_0^{1/2} + \mu^{1/2}\left(-\frac{du}{dr}\right)^{1/2}, \qquad \text{if } \tau \ge \tau_0 \qquad (9)$$

$$\frac{du}{dr} = 0 \qquad \text{if } \tau < \tau_0$$

$$\left(\frac{\partial u}{\partial r}\right) = 0 \quad \text{at} \quad r = 0 \qquad (10)$$
$$u = 0 \quad \text{at} \quad r = R(z)$$

SOLUTION OF THE PROBLEM

Solving for u from equation (8) and (9) and using boundary conditions (10), obtains,

$$
\begin{aligned}
& R_c \le r \le R \\
& \bar{u} = (\frac{R_e \varepsilon}{4\mu}(\frac{dP}{dz}))((R^2 - r^2 - \\
& \frac{8}{3}\frac{(R_c^{1/2} - r^{3/2})((r - R_c^{3/2})^2 + H^2)((r - R_c)^4 + H^2)(R - R_c)^2}{(1 + R_c{}^2)^2} \\
& + \frac{(4R^4{}_c + H^2)(r - R_c)(R - R_c)^2}{(1 + R_c{}^2)} r^4 + \frac{(5R_c + H^2)}{(1 + R_c{}^2)} r^2)^{3/2}(R - R_c)^2 \\
& + \frac{((R_c^{3/2} - r)^2 + H^2(r - R_c)^4)}{(4\mu)^{(1/2)}(1 + R_c{}^2)}(r^2 + \frac{(r - R_c)(8R_c + H^2)(R - R_c)^2}{(1 + R_c{}^2)} r^4 \\
& + \frac{(15(r - R_c) + (r - R_c)^3 H^2)(8(r - R_c) + H^2)(R - R_c)^2}{(1 + R_c{}^2)^2})^{3/2}) \\
& + (1 + \frac{(R - R_c)^2 H^2 (r - R_c)^2}{(1 + R^2)} + \frac{(8(r - R_c)^2 + H^2)H^2(R - R_c)^2}{(1 + R^2)^2})^{1/2} \\
& + \frac{(5R_c + H^2)(r - R_c)(R - R_c)^2}{(1 + R_c{}^2)} r^2)^{3/2})
\end{aligned}
\qquad (11)
$$

$$
\begin{aligned}
& 0 \le r \le R_c \\
& \bar{\bar{u}} = (\frac{R_e \varepsilon}{4\mu}(\frac{dP}{dz}))((R^2 - R_c{}^2 \\
& - \frac{8}{3}\frac{(R_c^{1/2} - R^{3/2})((R - R_c^{3/2})^2 + H^2)((R - R_c)^4 + H^2)}{(1 + R_c{}^2)^2}) \\
& + \frac{(15(R - R_c) + H^2)(8(R - R_c) + H^2)(R - R_c)^2}{(1 + R_c{}^2)^2})^{3/2}) \\
& + (1 + \frac{(R - R_c)^2 H^2 (R - R_c)^2}{(1 + R^2)} + \frac{(5R_c + H^2)}{(1 + R_c{}^2)} R^2)^{3/2}(R - R_c)^2)^{1/2} \\
& + (\frac{(4R^4{}_c + H^2)(R - R_c)^2}{(1 + R_c{}^2)} R_c{}^4 + \frac{(8H^2)H^2(R - R_c)^2}{(1 + R^2)^2} + \\
& + \frac{(5R_c + H^2)(R - R_c)^2}{(1 + R_c{}^2)} R_c{}^2)^{3/2}(\frac{((R_c^{3/2} - R)^2 + H^2)}{(4\mu)^{(1/2)}(1 + R_c{}^2)}(R_c{}^2 \\
& + \frac{(8R_c + H^2)(R - R_c)^2}{(1 + R_c{}^2)} r^4 +)
\end{aligned}
\qquad (12)
$$

The flow rate for the blood flow with transverse magnetic field is,

$$
Q = \int_0^R 2\,\pi\, u\, r\, dr \qquad (13)
$$

By the help of equation (11) and equation (12), flow rate can,

$$
\begin{aligned}
& Q = (\frac{R_e \varepsilon}{2\mu}(\frac{\partial P}{\partial z}))^{2/3}(\frac{(4\mu R_c)^{(2/3)}}{R^2} + \\
& \frac{(8(R_c/R)^2 + H^2)(8(R_c/R)^{2/3} + H^2)}{3(1 + R^2)} r^4 + \\
& \frac{(15R + H^2)(8(R_c/R)^2 + H^2)}{8R^2} + \\
& \frac{H^2(R_c{}^2/R)(2(R_c/R)^{2/3} + H^2)}{(1 + (R_c{}^2/R))} + \\
& \frac{(8(R_c/R)^{2/3} + H^2)H^4}{(1 + (R_c{}^2/R)^2)} + \\
& \frac{(5(R_c/R)^3 + H^4)(3(R_c/R)^{2/3} + H^2)(2(R_c/R) + H^2)}{(R_c{}^2/R)})^{2/3}
\end{aligned}
\qquad (14)
$$

From equation (14) pressure gradient is written as follows,

$$
\begin{aligned}
& \left(\frac{\partial P}{\partial z}\right) = (\frac{R_e \varepsilon}{2\mu} Q)(\frac{(\mu R)}{R_c{}^2} + \\
& \frac{(4 + H^2)(H^2 + 2)}{R_c{}^2} + \frac{(3(R_c/R)^{2/3} + H^2)(HR_e{}^2 + 1)^{2/3}}{(2 + R_c)^2} \\
& \frac{H^2 R_e R^2 (8(R_c/R)^{2/3} + H^2)}{(1 + R_c{}^2)} + \\
& \frac{(15R + H^2)(2\mu R + H^2)}{(1 + R_c{}^2)^2} + \frac{3(2 + R^2)(3H^2 + 8)(R_c/R)^{2/3}}{R_c{}^4}) \\
& + \frac{(5(R_c/R)^3 + H^4)(2(R_c/R) + H^2)H^3 R_e R}{(R_c{}^2/R)(1 + R_c{}^2)})^{2/3} \\
& + \frac{(15R + H^2)(8(R_c/R)^2 + H^2)}{8R^2}
\end{aligned}
\qquad (15)
$$

The dimensionless expression for resistance to flow, using

$$
\lambda = \left(\frac{P_i - P_0}{Q}\right), \qquad (16)
$$

Using the boundary conditions, P_i is pressure at z = 0 and P_0 is the pressure at z = L. The resistance to flow can be written as,

$$
\begin{aligned}
& \lambda = -\left(\frac{HR_e \varepsilon}{n\pi}\right)^{2/3} \frac{L_0}{4\pi R_0}\frac{7\delta^2}{8R_0^2} A_1 \\
& \left((L-d)\frac{5\delta}{2R_0} - 1\right)\frac{L_0}{4\pi R_0}\frac{7\delta^2}{8R_0^2}\left(\frac{L_0}{2}\right) \\
& + \frac{L_0}{2\pi R_0} A_1 \left(\frac{20\delta^2 (L-d)^{(m+1)}}{4R_0^2} - \frac{5\delta}{2R_0}\right) \\
& (1 - \frac{3\delta}{2R_0} + \frac{9\delta(L-d)^{(m+2/3)}}{8R_0^2} \\
& + A_1\left(\frac{5\delta}{2R_0} - 1\right))^{2/3} \\
& + \frac{3\delta(L-d)^{(m+1)}}{2R_0} + \frac{6\delta^2(L-d)^{(m+1)}}{4R_0^2} \\
& + \frac{L_0(L-d)^{(m+1)}}{4\pi R_0}\frac{7\delta^2}{8R_0^2}\left(\frac{L_0}{2}\right) + \\
& \frac{L_0}{2\pi R_0}(\frac{3\delta_S}{2R_0} A_1 \left(\frac{5\delta}{2R_0} - 1\right) \\
& - \frac{6\delta^2(L-d)^{(m+1)}}{4R_0^2} + \\
& A_1\left(\frac{20\delta^2}{4R_0^2} - \frac{5\delta(L-d)^{(m+1)}}{2R_0}\right))^{2/3} \\
& \left((L-d)^{(m+1)} - \frac{L_0}{2}\right)^{2/3} \\
& + \left((L-d)^{(m+1)}\right)^{2/3} \frac{L_0}{2\pi R_0}((\frac{\delta_S}{2R_0}\left(\frac{5\delta}{2R_0} - 1\right) \\
& - \frac{2\delta^2}{5R_0^2}\frac{L_0}{2\pi R_0})(\frac{3\delta}{2R_0} + \frac{6\delta^2}{4R_0^2} \\
& + A_1\left(\frac{20\delta^2}{4R_0^2} - \frac{5\delta^2(L-d)^{(m+1)}}{2R_0}\right))^2 + \\
& A_1\left(\frac{(L-d)^{(m+1/2)}\delta^2}{3R_0^2} - \frac{5\delta}{2R_0}\left(\frac{5\delta}{2R_0} - 1\right)\right))^{3/2}
\end{aligned}
\qquad (17)
$$

where
$$A_1 = R_e\varepsilon(R^2 + \frac{(8+H^2)R^4}{(1+R^2)^{1/2}} + \frac{(8+H^2)(15+H^2)R^6}{(1+R^2)^{2/3}})/(\frac{H^2R^2}{(1+R^2)} + \frac{\left(8+H^2\right)H^2R^4}{(1+R^2)^2})^{1/2}$$

The shearing stress at the wall can be written as,

$$\tau = (-\mu(\frac{\partial P}{\partial Z}))^{3/2} R_e\varepsilon((\frac{2R_eH^2}{R^2} + \frac{4R^3\left(5+H^2\right)}{\left(1+R^2\right)^{1/2}}\frac{\left(8+H^2\right)\left(15+H^2\right)}{\left(2+R^2\right)^{3/2}})^{3/2} + \frac{2R^{1/2}{}_eH^2}{R^3}\frac{\left(8+H^2\right)\left(2+H^2\right)}{\left(1+R^2\right)^4} \frac{2R^2(8+H^3)}{\left(2+R^2\right)^{3/2}}\frac{4R^3\left(3+H^2\right)}{\left(1+R^2\right)^2} + (\frac{2R^2(2+H^3)}{\left(1+R^2\right)}\frac{4R^3\left(5+H^2\right)}{\left(1+R^2\right)^2})^{1/2} + \frac{6R_e{}^2H^2(2+H^2)}{R^2}\frac{4R^3\left(2+H^3\right)}{\left(2+R^2\right)^4} + \frac{4R^3\left(5+H^2\right)}{\left(1+R^2\right)} + \frac{\left(3+H^2\right)\left(15+H^2\right)}{\left(1+R^2\right)^{3/2}} + \frac{4R^3\left(2+H^2\right)}{\left(2+R^2\right)^{1/2}} + \frac{\left(15+H^2\right)^2}{\left(1+R^2\right)^{1/2}}) \quad (18)$$

RESULTS AND DISCUSSION

In order to have estimate of the quantitative effects of various parameters such as Hartmann number (H= 0, 0.2, 0.6, 1), red cell (M = 0, 2, 4), stenosis shape parameter (m= 2...11) involved in the analysis computer codes were developed and to evaluate the analytical results obtained for resistance to blood flow, velocity profile and wall shear stress for diseased system associated with stenosis due to the local deposition of lipids have been determine. The results are shown in Fig 2-6 by using the values of parameter based on experimental data in stenosed artery.

Fig. 2 depicts the variation of axial velocity with radial co-ordinate. It is clear from the figure that of magnetic field reduces the velocity of blood. The development of stenosis accelerates the velocity of plasma between the cells. This in turn increases the concentration of red cell and viscosity of blood in stenotic region, therefore increases. Our results are similar to [11]. Therefore magnetic field can be effectively utilized to deaccelerate the blood flow in flow problems.

The variation of resistance to flow (λ) with stenosis size (δ/R_0) for different values of Hartmann number (H) and red cell parameter (M) are shown in Fig. 3. It is evident that resistance to flow increases as stenosis size increases. Increase in the resistance to flow with red cell is also indicated in the figure. Resistance to flow increase as stenosis grows or radius of artery decreases (this referred to as Fahraeus-Lindquist effect in very thin tubes). It is also shown in figure that the resistance to flow decreases with increasing value of Hartmann number. Mazumdar [9] found that the resistance of blood in diabetic patients is higher than in non-diabetic patients, resulting higher resistance to blood flow in the presence of magnetic effect. Thus diabetic patients with higher resistance to flow 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. These results are consistent with the observation of [15].

Fig.4 shows the results for resistance to flow for different values of stenosis shape parameter (m), Hartmann number (H) and red cell parameter (M). Resistance to flow decreases as stenosis shape parameter increases and decreases as Hartmann numbers (H) increases. It is also shown in figure that the resistance to flow increases with increasing value of red cell parameter (M).

Fig.5 shows the results for resistance to flow with stenosis length, for different values of Hartmann numbers and red cell parameter. Resistance to flow increases as stenosis length increases and decreases as Hartmann numbers (H) increases. It is also shown in figure that the resistance to flow increases with increasing value of red cell parameter. In a healthy artery, the wall shear stress is approximately 15 dyn / cm^2. The interior surface will be damaged once the wall shear stress reaches a value higher than 400 dyn / cm^2 [7]. Therefore to determine the critical flow condition, prediction of wall shear stress using numerical experiments become necessary.

To capture the results for wall shear stress in the presence of externally applied magnetic field, the graphs have been plotted in figure 6. The graph shows the results for wall shear stress (τ) for different values of Hartmann numbers (H), red cell parameter (M) and stenosis size (δ/R_0). Wall shear stress (τ) increases as stenosis size increases and decreases as and Hartmann number (H) increases. It is concluding from these results that the wall shear stress (τ) increases as the stenosis grows and remains constants outside from the stenotic region. It is also seen that wall shear stress is decreases when an external magnetic field is applied. This result is qualitative agreement with the observation of [8, 11]. It is observed that reduction in velocity, resistances to flow and wall shear stress are more pronounced in central region of the pipe and results are compared with [10].

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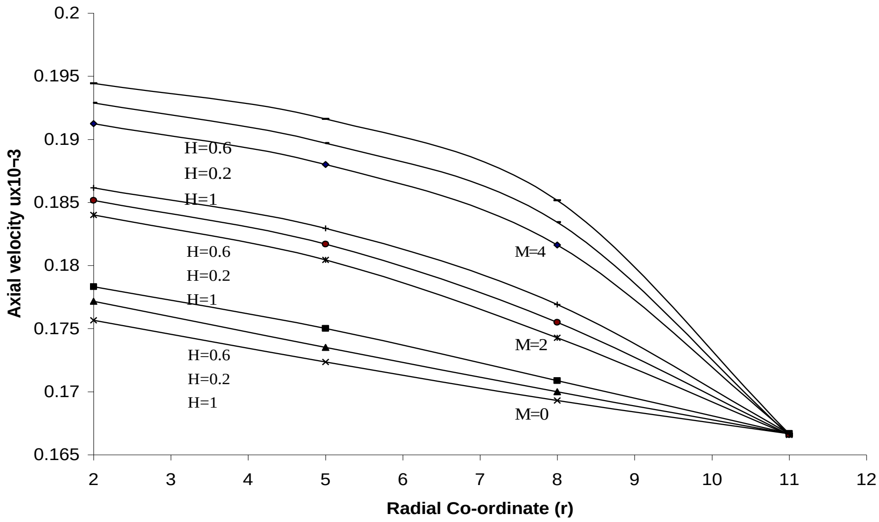

Fig. (2) Variation of axial velocity with radial co-ordinate

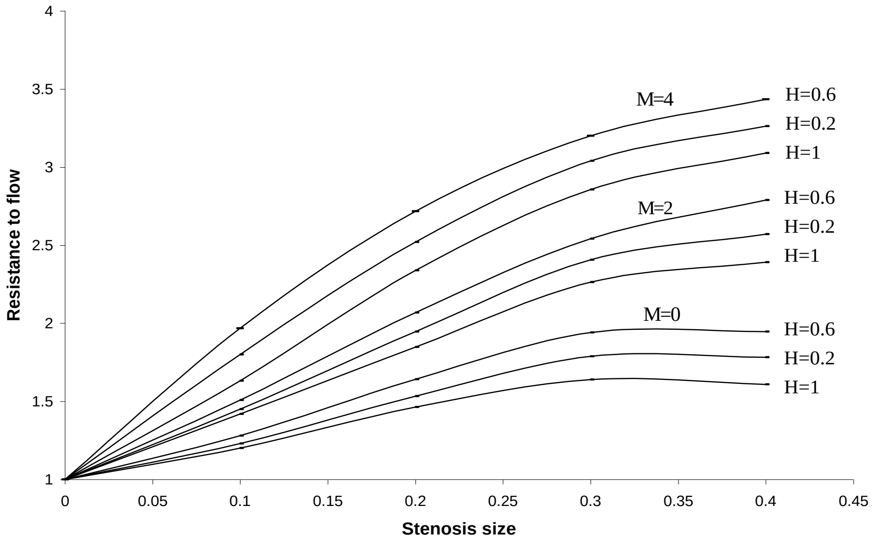

Fig. (3) Variation of resistance to flow with stenosis size

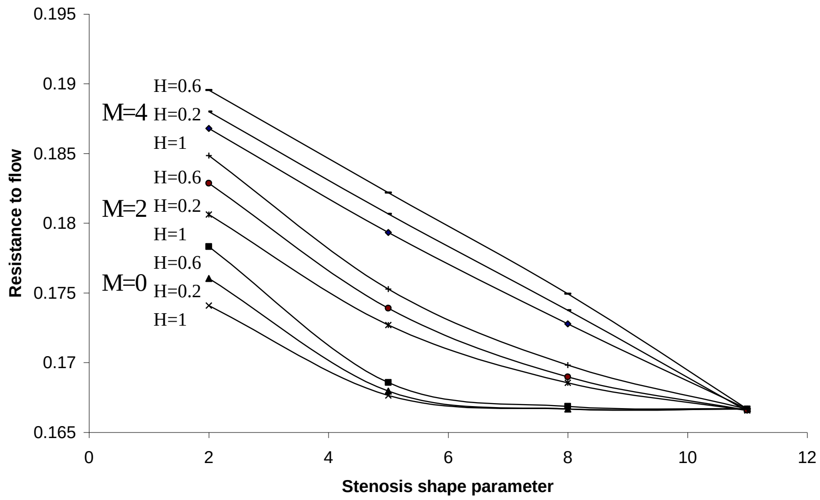

Fig. (4) Variation of resistance to flow with stenosis shape parameter for different H

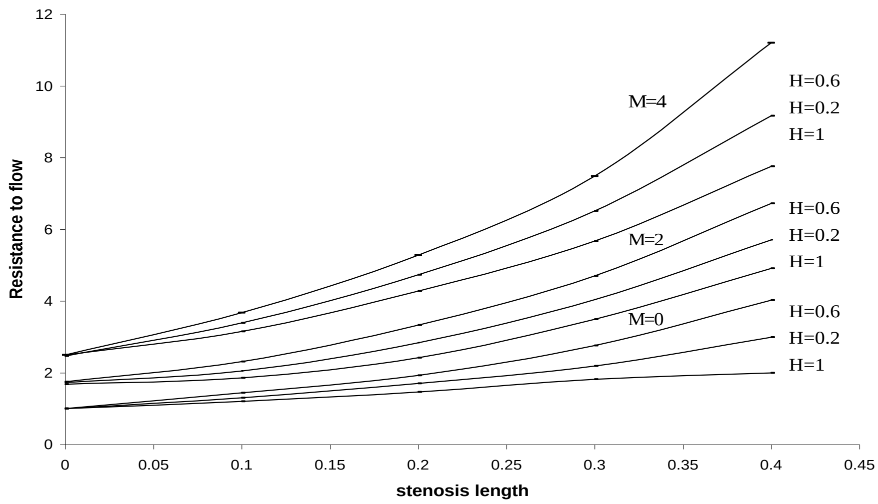

Fig. (5) Variation of resistance to flow with stenosis length

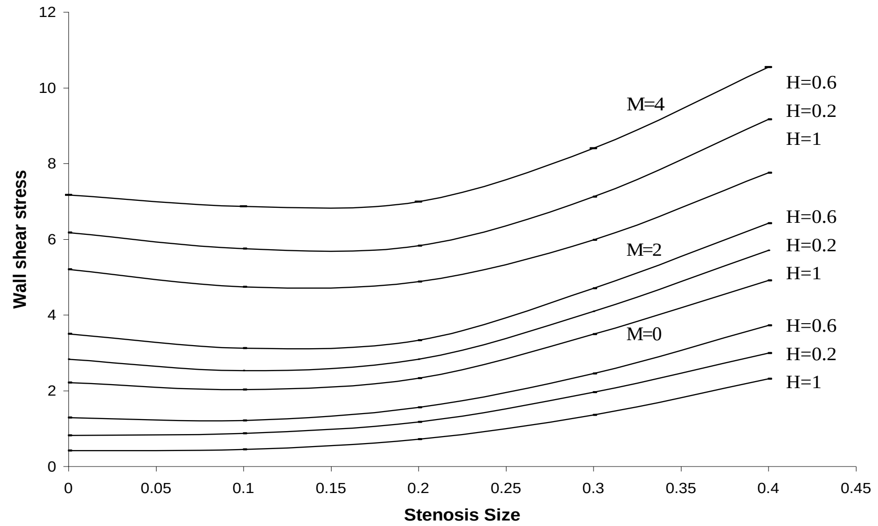

Fig. (6) Variation of Wall shear stress with Stenosis Size

CONCLUSIONS

Resistance to flow increases as the stenosis grows and remains constant outside the stenotic region. If resistance to flow increases, it is more difficult for the blood to pass through an artery, result the flow decreases and heart has to work harder to maintain adequate circulation. In this present study, velocity profile, resistance to flow and wall shear stress are obtained when blood is assuming as Casson's fluid model, electrically conducting fluid, so that the effect of magnetic field on blood flow through an artery can be observed. Looking at the importance of the hydrodynamic factors in the understanding of blood flow and atherosclerotic diseases, it may be said that the present model could be useful for investigating blood flow through stenosed artery, in particular in diseased stage when blood is no longer a Newtonian fluid; it has stress with magnetic effects. It is noticed that the resistance to blood flow and wall shear stress decreases for different magnetic fields and also decreases as stenosis shape parameter increases. The magnetic field is to decrease the resistance to flow due to irregular boundaries. So the magnetic field can be effectively utilized to deaccelerate the blood flow in flow problems. The present study is able to predict the main characteristic of the physiological flows and may have played some important role in biomedical application.

REFERENCES

[1] Young DF: Effect of a time-dependent stenosis of flow through a tube, J. Eng. Ind. (1968) 248-254.

[2] Nerem RM: Fluid dynamics aspects of arterial disease, In proceeding of a specialist meeting at Ohio University held in sept. (1974) 19-20.

[3] Haldar K: Effect of the shape of stenosis on the resistance to flow through an artery, Bull. Math. Bio. 47 (1985) 545-550.

[4] Bitoun JP and Bellet D: Blood flow through a stenosis in microcirculation, Biorheol. 23 (1986) 51-61.

[5] Chakravarty S: Effect of stenosis on flow behaviour of blood in an artery, Int. J. Eng. Sci. 25 (1987) 1003-1016.

[6] Srivastava VP and Saxena M: Two-layered model of Casson's fluid flow through stenotic blood vessels: application to cardiovascular system, J Biomech. 27 (1994) 921-928.

[7] Srivastava LM: Flow of couple stress fluid through stenotic blood vessels, J Biomech. 18 (1985) 479-485.

[8] Srivastava VP: Particulate suspension blood flow through stenotic arteries: Effect of Hematocrit and stenosis shape, I. J. Pure Appl. Math. 33(9) (2002) 1353-1360.

[9] Mazumdar HP, Ganguly UN and Venkatesan SK: Some effects of magnetic field on flow of a Newtonian fluid through a circular tube. Indian J Pure and Appl. Math. 27 (5) (1996) 519-524.

[10] Tandon PN and Pal TS: Applied magnetic field effects on pulsatile blood through a time developing stenotic tube, Proc 16th national Conf. Fluid Mech. and fluid power. (1988).

[11] Sud VK, Suri PK and Mishra RK: Effect of magnetic field on oscillating blood in arteries, Studia Biophysica, 46 (1974)163-169.

[12] Mazumdar HP Ganguly UN and Venkatesan SK: Some effects of magnetic field on the flow of a Newtonian fluid through a circular tube, Indian J. Pure and Appl. Math.27 (5) (1996).

[13] Barnothy MF: Biological Effects of Magnetic Fields, (1,2) Plenum Press, (1969).

[14] Sud VK and Sekhon GS: Blood Flow through the Human Arterial system in the presence of a steady magnetic field, Phys. Med. Biol, 34(1989) 36-42.

[15] Tzirtzilakis EE: A mathematical model for blood flow in magnetic field, Phys. Fluids 103 (2005) 77-103.

[16] Amos E and Ogulu A: Magnetic effect on pulsatile flow in a constricted axissymmetric tube. Indian J. Pure and appl. Math. 34(9) (2003) 1315-1326.

[17] Haldar K and Ghosh SN: Effect of Magnetic field on blood flow through an indented tube in the presence of eeythrocytes, Indian. J. Pure appl. Math. 25(3) (1994) 345-352.

[18] Secomb TW Pries. AR, Blood flow and red blood cell deformation in non-uniform capillaries: effect of endothelial surface layer. Microc. 9, (2005) 189-196

[19] Vittorio C and Ghassan, SK: Computer Modeling of red blood cell Rheology in the Microcirculation: A Brief Overview. Life Science, 33 (2008) 1-4.