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Mathematical model of blood flow through stenosed arteries with the impact of hematocrit on wall shear stress

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Abstract
The flow of blood through stenosed arteries has been studied in this paper. I have developed and solved some theoretical formulas based on stenosis and effects of hematocrit. The purpose of this study to observe the impact of Hematocrit namely red blood cells, height of stenosis, porous parameter and velocity slip on wall shear stress in the blood flow through stenosed arteries. It is found that for increasing Hematocrit percentage then wall shear stress reduces. The variations of wall shear stress with other parameters are shown graphically.

Keywords: Hematocrit, porous parameter, velocity slip, stenosis, wall shear stress

Introduction
Blood is essential for maintaining the health and life of the human body. Blood is made up of red blood cells, white blood cells and platelets, suspended in plasma. Red Blood Cells (RBCs) are more than a thousand times more numerous than the White Blood Cells (WBCs) and much larger than platelets. So the flow properties of blood particularly depend on the RBCs. Hematocrit is the percentage by volume of red cells in our blood. It is the major determinant of blood viscosity. Initially red blood cells have round in shape. The hematocrit, also known by various names, is the volume percentage of red blood cells in blood, measured as part of a blood test. The measurement depends on the size and number of red blood cells. It is normally 40.7%–50.3% for males and 36.1%–44.3% for females. This value can be determined directly by micro hematocrit centrifugation or calculated indirectly. Automated cell counters calculate the hematocrit by multiplying the red cell number (in millions/mm3) by the mean cell volume (MCV, in femtoliters). Hematocrit level of the blood flow in the artery depends upon the diameter of the artery, and this relationship has important implications for physiological phenomena related to blood flow.

The circulation system is an organic system which permits blood to circulate and transport nutrients (such as electrolytes and amino acids), blood cells, oxygen, hormones, carbon-di-oxide from the cells in our body to provide nourishment and help in fighting diseases, stabilize temperature and PH, and maintain homeostasis. The condition where the artery becomes narrowed and hardened due to the deposition of excessive fatty components (cholesterol) and abnormal intravascular growth which results in the formation of the stenosis is called the atherosclerosis. This may be caused by unhealthy living conditions such as exposure to tobacco smoke, lack of physical activity and improper dietary habits. The atherosclerotic cardiovascular disease is the usual cause of heart attacks, strokes and peripheral vascular disease. This has been the major causes of health problems and death in this 21st century globally. The world health organization (WHO) gave an estimation of 17.9 million of people who died from atherosclerotic cardiovascular disease in 2016, which represent 31% of all global deaths, 85% are due to heart attack and stroke. It is always followed by the serious changes in blood flow, pressure distribution, wall shear stress and flow resistance.

A lot of work is available in this direction. Kumar and Diwakar (2013) [9] investigated hematocrit effects of the axisymmetric blood flow through an artery with stenosis arteries. In their investigation, they observed that the effects of hematocrit on blood flow characteristics in the presence of stenosis, and also found that the resistance of flow and the wall shear stress increases with hematocrits. Babatunde and Dada (2021) [15] studied on the effects of hematocrit level on bblood flow through a tapered and overlapping stenosed artery with porosity and they found that the flow resistance increases with an increase in either height of stenosis or structures of artery while it slightly decreases as hematocrit level increases. They also observed that there is no stenosis on significant different in hematocrit level, slip-parameter, Darcy number and stenosis height for wall shear stress. When wall shear increases then the artery shapes decreases in stenosis region. They also concluded that the wall shear stress increases when stenosis height increases at the middle. Malek and Hoque studied Hematocrit Level on Blood flow through a Stenosed Artery with Permeable Wall and highlighted that for the increasing of stenosis height and the hematocrit level (35%-45%) has significant effects then resistance of flow increases. Singh and Singh (2013) proposed the effect of hematocrit on wall shear stress for blood flow through tapered artery. In their theoretical modeling they concluded that wall shear stress reduces for increasing of hematocrit percentage. They also noticed that when height of stenosis and porous parameter increases then wall shear stress increases.

Moreover, the wall shear stress decreases as increasing values of blood velocity and slope of tapered artery. Srivastava and Rastogi (2009) [6] investigated blood flow through a stenosed catheterized artery: Effects of hematocrit and stenosis shape. In their theoretical study they observed that the impedance increases with the catheter size, the hematocrit and the stenosis size (length and height) but the shape parameter decreases. Biswas and Chakraborty studied impact of hematocrit and slip velocity on pulsatile blood flow on constricted tapered artery. Due to a wall slip, the wall shear stress and effective velocity decreases with axial velocity increases. The effective velocity and wall share stress are much higher for the influence of hematocrit. But Kumar *et al.* (2021) [16] gave an idea on comparative study of non-Newtonian physiological blood flow through elastic stenotic artery with rigid body stenotic artery. Although Onitilo *et al.* (2020) [13] analysed effects of hematocrit on blood flow through a stenosed human carotid artery. They discovered that the hematocrit level increases then the resistance increases. Also, they concluded that the wall shear stress decreases with the increase in the level of hematocrit of the red blood cells. Jimoh *et al.* (2019) gave an idea on hematocrit and slip velocity influence on third grade blood flow and heat transfer through a stenosed artery. They observed that flow velocity and volumetric flow rate decrease while shear stress, heat transfer rate, and resistance to flow increase when the hematocrit parameter increases. Srivastava and Rastogi (2009) studied effects of hematocrit on impedance and shear stress during stenosed artery catheterization. They found that for any given catheter size, the impedance increases with hematocrit. The variations in the magnitude of the shear stress at stenosis throat have opposite characteristics in comparison to the variations of flow resistance.

The present study is motivated towards a theoretical investigation ofblood flow through stenosed arteries with the impact of hematocrit on wall shear stress. The study pertains to a situation in which the wall share stress depending upon hematocrit is taken into consideration. The present model is designed for the deformation of stenoses with aid of drug release models in human arteries. Thus, this study will answer the question of mechanism of further deposition of plaque under various aspects.

Mathematical formulation

Physical model of stenosed artery is

$$R(z)=\begin{cases} R_1 - m(z+l) \\ R_1 - m(z+l)\frac{h\cos\emptyset}{2}\left\{1+\cos\left(\frac{\pi z}{l_0}\right)\right\} \\ R_1 - m(z+l) \end{cases}$$

$0 \leq z \leq d$
$d \leq z \leq d + l_0$
$d + l_0 \leq z \leq l$ (1)
$\leq z \leq +$

$R(z)$ = Effective radius of stenosed artery
R_1 = Radius of stenosed Artery
$\emptyset$ = Angle of Tapering
$H = h\cos\emptyset$ = the height of stenosed artery
l_0 = length of stenosis
$m = \tan\emptyset$ = Slope of stenosed vessel

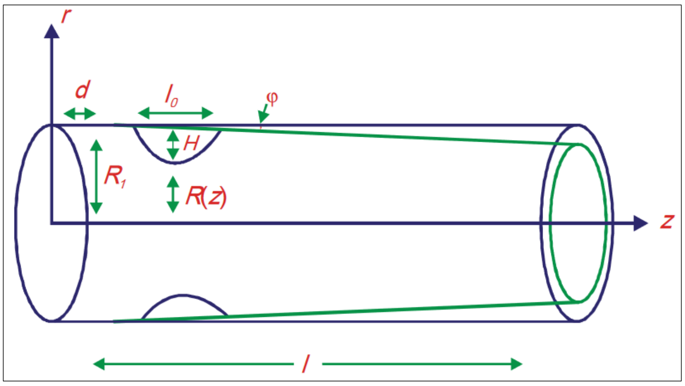

Fig 1: Physical model of tapered artery

For a Newtonian fluid

$$\tau = \frac{rG}{2} \quad (2)$$

From Darcy's Law

$$q = -\frac{kG}{\rho} \quad (3)$$

From equation (2) and (3), we have:

$$\tau = -\frac{\rho q}{2k} r$$

To find the effect of hematocrit on the wall shear stress, the relation of viscosity of blood and the hematocrit is given by:

$$\rho = \rho_p(1 + 2.5H)$$

The wall shear stress through the artery is given by

$$\tau = -\frac{\rho_p(1+2.5H)q}{2k}\int_0^l R(z)\ dz$$

Or,

$$\tau = -\frac{\rho_p(1+2.5H)q}{2k}\left[\int_0^d \{R_1 - m(z+l)\}dz + \int_d^{d+l_0}\left[R_1 - m(z+l) - \frac{h\cos\emptyset}{2}\left\{1+\cos\left(\frac{\pi z}{l_0}\right)\right\}\right]dz + \int_{d+l_0}^{l}\{R_1 - m(z+l)\}dz\right]$$

Or,

$$\tau = -\frac{\rho_p(1+2.5H)q}{4k}(a+b+c)$$

Where, $a = [(R_1 - ml)^2 - \{R_1 - m(d+l)\}^2]$

$b = [\{R_1 - h\cos\emptyset - m(d+l)\}^2 - \{R_1 - m(d+l_0+l)\}^2]$

$c = [\{R_1 - m(d+l_0+l)\}^2 - (R_1 - 2ml)^2]$

Results and discussion

It is seen that from figure (2), (3) and (4), the stenosis height $H = h\cos\emptyset$ and porous parameter increases then wall shear stress also increases but, wall shear stress decreases as the blood velocity increases. Further that as the hematocrit percentage increase wall shear stress diminishes in the present situation. Therefore, by adjusting the percentage of hematocrit, one can control the wall shear stress to maintain the arterial diseases under stenotic condition.

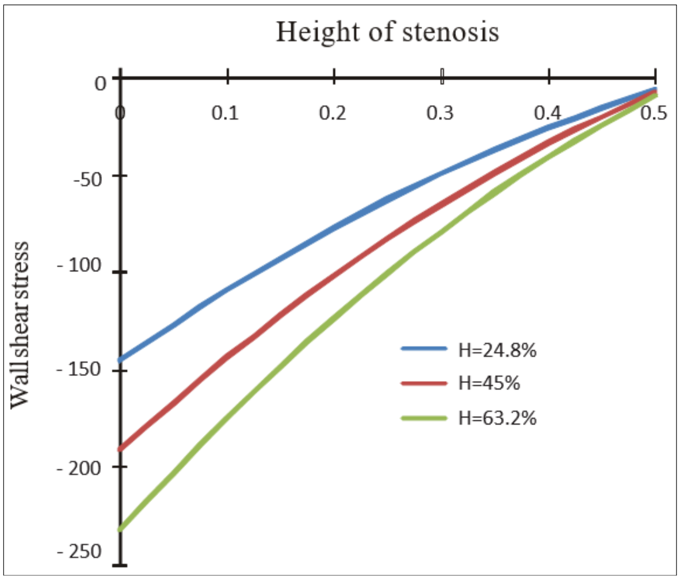

Fig 2: Variation in wall shear stress with stenosis height for different Hematocrit percentage

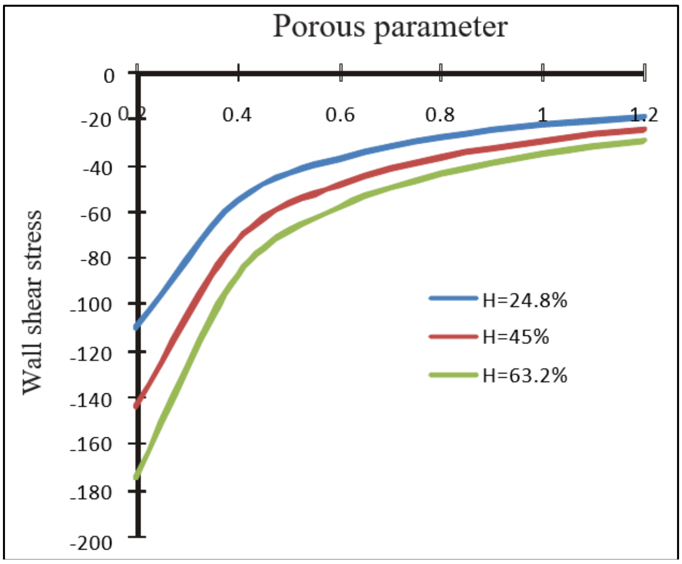

Fig 3: Variation in wall shear stress with porous parameter for different hematocrit percentage

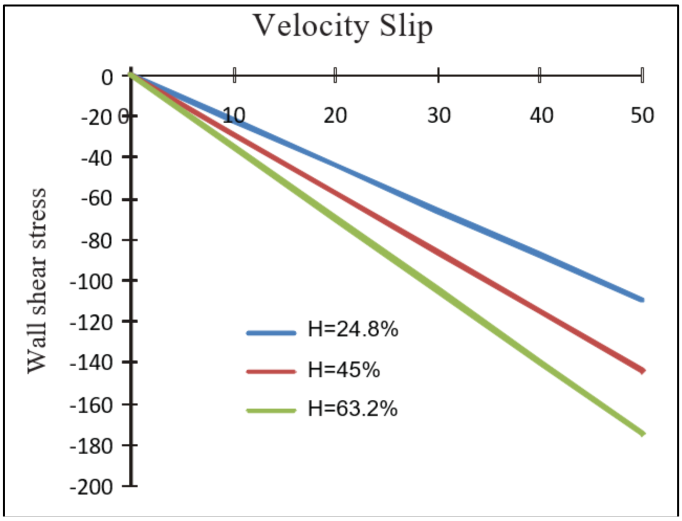

Fig 4: Variation in wall shear stress with velocity slip for different hematocrit percentage

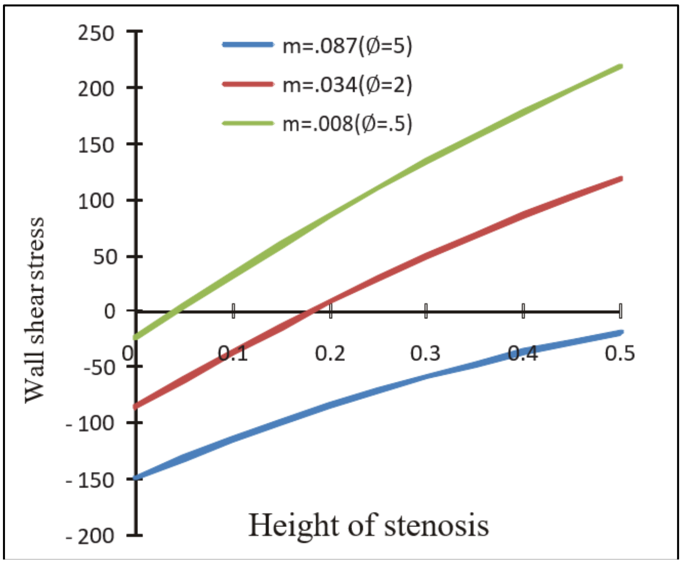

Fig 5: Variation in wall shear stress with stenosis height for different slopes of stenosed artery.

It is also noted from the figure (5) that the increase in slope of stenosed artery wall shear stress decreases.

Conclusion

Wall shear stress plays an important role in long term maintenance of the structure and function of the blood vessel. Under normal conditions, shear stresses maintain their direction and their magnitude within a range of values that impedes atherogenesis, thrombosis, adhesion of leukocytes, smooth muscle proliferation and endothelial apoptosis. Changes in shear stress magnitude activate cellular proliferation mechanisms as well as vascular remodelling processes. More specifically, a high grade of shear stress increases the thickness of wall and expands the artery diameter so that shear stress values return to their normal values. In contrast, low shear stress induces a reduction in diameter. It is also observed that wall shear stress increases as height of stenosis and porous parameter increase whereas it decreases with the increasing values of velocity of blood and slope of stenosed artery.

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