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A STUDY ON RHEOLOGICAL BEHAVIOR OF BLOOD: AN ALTERNATIVE APPROACH

Dr. Naresh Kaul
MD Aspirant & Physician
Mangaluru, INDIA.

ABSTRACT

The study of hemorheology has become an important field in biomedical research. Blood is a complex substance and it performs various functions in the human body. The blood viscosity plays an important role which affects the flow of blood. This study proposes a simple and new technique to find out the viscosity of blood at different flow rates by using normal capillary tube. The tool is developed based on the Poiseuille's theory to measure the coefficient of viscosity and volume flow rate of blood for different radii. The simple method developed in the laboratory can serve as a potential tool in the absence of sophisticated rheological or viscometric equipment.

KEY WORDS : Hemorheology, blood, viscosity, flow rate

INTRODUCTION

Rheology is the study of the flow and deformation behavior of materials. It is a specialized part of fluid mechanics and is concerned primarily with non-Newtonian substances like Blood. Blood is a vital fluid found in human beings and other animals. It contains many chemical compounds to perform various functions. Healthy blood varies in viscosity as it flows normally and becomes much thinner by the time it reaches the capillaries.

From a hemorheological point of view, fluids can be divided into two main groups
(1) Newtonian fluids, (2) Non-Newtonian fluids.

A Newtonian fluid (named after Isaac Newton) is a fluid whose stress versus strain rate curve is linear and passes through the origin. That is, the relation between the shear stress and the strain rate is linear. The coefficient of viscosity is the constant of proportionality. Water is an example of a Newtonian fluid.

A Non-Newtonian fluid is a fluid whose flow properties are not described by a single constant value of viscosity. Many polymer solutions and molten polymers are non-Newtonian fluids. The commonly used substances like ketchup, paint, blood and shampoo are come under non-Newtonian fluids.

Although the concept of viscosity is commonly used to characterize a material, it is not adequate to describe the mechanical behavior of a substance, particularly non-Newtonian fluids. They have several other rheological properties, which describe the relations between the stress and strain rate tensors for different flow conditions.

VISCOSITY

Viscosity is a measure of the resistance of a fluid, which is being deformed by either shear stress or tensile stress. In other words, Viscosity means the degree of stickiness of a liquid. The viscosity of healthy blood is low therefore it flows freely. High blood viscosity slows down the circulation and reduces oxygenation of tissues.

THE FLOW RATE

The flow rate of blood also affects viscosity. At very low flow rates in the microcirculation the blood viscosity can increase significantly. This is because at low flow rates there are increased cell-to-cell and protein-to-cell adhesive interactions which causes erythrocytes to adhere to one another and increase the blood viscosity.

MATERIALS AND METHODS

To study the rheological behavior of blood, a simple capillary technique is used. Though Capillary viscometry is the most traditional method for measuring the viscosity of the viscous materials, here in the present study, an open-end capillary viscometer is used and a theory is developed based on the Poiseuille's theory for the dynamics of a liquid column in an open capillary tube. No external pressure is applied on the liquid column. The pressure at the two ends of the capillary tube is the atmospheric pressure.

The simple capillary viscometric technique, which is employed in this study, is used to measure both viscosity and volume flow rate. For this study the quantity of sample required is about 5ml. Fresh samples of normal human blood were collected from the diagnostic centre. The anticoagulant, Ethylene Diamine Tetra Acetic acid (EDTA) is used.

Plasma was separated from blood by centrifuging the blood at the rate of 1500 rmp about 10 to 15 minutes. By taking out the plasma, RBC (90% packed erythrocytes) was separated. Blood samples were prepared by mixing an equal amount of plasma and erythrocytes. By this process, Hematocrit of sample is maintained to be constant.

EXPERIMENTAL PROCEDURE

The open-end glass capillary tube was marked with two preset points A and B and the distance between them is 10cm. It was clamped vertically to a stand. A sample of blood of length 2 to 8cm was sucked by one end of the capillary tube. The pinchcock arrangement controls the movement flow of liquid column between the preset terminals. The vertical clamping of the capillary tube with sample will set the liquid column into one-dimensional motion. At the beginning of the experiment, meniscus of column was set above the marked point A (upper mark). The timer was switched on the moment the meniscus of the liquid column passed the mark A, when the pinchcock was released. The timer was switched off now the meniscus passed off mark B (lower mark). The timer records the time of the sample, which travelled 10cm distance. The velocity was calculated from the ratio of the preset distance (10cm) and time. For different lengths of the liquid column, the time of travel was recorded and velocity was calculated. A plot was drawn between L^{-1} on X-axis and V on Y-axis. The plot is a straight line with an intercept on Y-axis. The intercept of the straight line was measured which gives the maximum velocity. Viscosity and volume flow rate of the sample were calculated from the intercept of the straight line, respectively, with the known radius of the capillary tube (R). The radius of the capillary tube (R) was measured using a travelling microscope having Least Count (L.C) of 0.001 cm.

To examine the validity of the proposed technique, the parameters-viscosity and volume flow rates are determined for water whose values are taken as standard from literature.

Table.1 shows the data on specific gravity of water. Five samples of water are taken and found the specific gravity. The values are tabulated and compared with the standard value. They are in good agreement. The mean and standard deviation are also calculated and mentioned below the table

Table.1: Data on Specific gravity of Water

Sample Code	Specific gravity
W1	1.023
W2	1.023
W3	1.024
W4	1.024
W5	1.023

Mean: 1.023: S.D=± 0.0005

Table.2 gives the data on specific gravity of human blood. Five samples of human blood were collected and found the specific gravity. The values when compared with the standard values, they are in good agreement. Mean and standard deviation are also found and shown below in the table.

Table.2: Data on Specific gravity of Human Blood.

Sample Code	Specific gravity
HB_1	1.057
HB_2	1.058
HB_3	1.062
HB_4	1.061
HB_5	1.064

Mean: 1.060 : S.D= ± 0.0029

Table.3: Data on coefficient of Viscosity of Water

CT=Capillary Tube
CT1= 0.029cm; CT2= 0.040cm; CT3= 0.045cm; CT5= 0.055cm

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Sample Code	Viscosity, η (poise)			
	CT1	CT2	CT3	CT4
W1	0.012	0.012	0.012	0.012
W2	0.012	0.012	0.012	0.012
W3	0.013	0.013	0.013	0.013
W4	0.013	0.013	0.013	0.013
W5	0.012	0.012	0.012	0.012

Mean: 0.012 Mean: 0.012 Mean:0.012 Mean: 0.012

S.D= ±0.0005 S.D= ± 0.0005 S.D= ±0.0005 S.D= ± 0.0005

Table .4 shows the data on coefficient of viscosity of human blood. The fresh samples of blood were collected and found the viscosity for four different radii i.e. 0.029cm, 0.040cm, 0.045cm and 0.055cm of capillary tubes. It is observed from the table that as the radius of the capillary tube increases, the coefficient of viscosity also increases.

Table 4: Data on coefficient of Viscosity of Human Blood

Sample Code	Viscosity, η (poise)			
	CT1	CT2	CT3	CT4
HB1	0.02427	0.02663	0.02889	0.03927
HB2	0.02126	0.02399	0.03393	0.0434
HB3	0.02184	0.02308	0.03009	0.04825
HB4	0.02663	0.03055	0.03505	0.04849
HB5	0.02951	0.03062	0.03551	0.05101
HB6	0.02569	0.039	0.03924	0.04541
HB7	0.02569	0.02926	0.03414	0.04732
HB8	0.02539	0.02968	0.03414	0.04014
HB9	0.03765	0.03405	0.04045	0.04243
HB10	0.02951	0.03582	0.03984	0.04043
HB11	0.03368	0.03516	0.03804	0.04227
HB12	0.02968	0.03057	0.0364	0.03889
HB13	0.02473	0.03595	0.03677	0.04611
HB14	0.02299	0.02971	0.03553	0.04237
HB15	0.02698	0.02873	0.03286	0.04732
HB16	0.02299	0.02846	0.03553	0.0479
mean	0.027	0.031	0.035	0.044
S.D=±	0.0044	0.0044	0.0032	0.0038

Table 5. shows the data on volume flow rate of water. For five samples of water four different radii of i.e.0.029cm, 0.040cm, 0.045cm and 0.055cm of capillary tubes were taken to find out the volume flow rate. It is observed from the given table that the flow is continuous when the length is infinite.

Table .5: Data on Volume flow rate of water

Sample Code	Volume flow rate, Q (cm3 sec-1)			
	CT1	CT2	CT3	CT4
W1	0.035	0.06757	0.08552	0.12775
W2	0.033	0.06406	0.08107	0.12111
W3	0.031	0.06029	0.076302	0.113982
W4	0.035	0.066819	0.084568	0.126335
W5	0.032	0.061041	0.077255	0.115406
Mean	0.034	0.064	0.081	0.121
S.D= ±	0.0017	0.0033	0.0042	0.0062

Table 6 gives the data on volume flow rate of human blood. Four capillaries with different radii i.e.0.029cm, 0.040cm, 0.045cm and 0.055cm were used for different samples of blood and the flow rate was found. It is clear from the table that the flow rate increases with the increases of the radii of capillary tubes.

Table 6: Data on Volume flow rate of Human Blood

Sample Code	Volume flow rate, Q (cm3 sec-1)			
	CT1	CT2	CT3	CT4
HB1	0.01188	0.03918	0.05786	0.06498
HB2	0.01188	0.03173	0.04955	0.06082
HB3	0.0132	0.04521	0.0561	0.07844
HB4	0.01082	0.03416	0.04768	0.07693
HB5	0.01293	0.0371	0.05086	0.07313
HB6	0.01199	0.04069	0.04924	0.08216
HB7	0.01122	0.03567	0.04896	0.07883
HB8	0.01135	0.035	0.04896	0.06319
HB9	0.01165	0.03064	0.04133	0.06174
HB10	0.00977	0.0305	0.04433	0.06174
HB11	0.01101	0.0331	0.04289	0.0617
HB12	0.01147	0.03516	0.04942	0.07313
HB13	0.01103	0.0331	0.04673	0.06648
HB14	0.01154	0.0376	0.04705	0.07123
HB15	0.01158	0.0301	0.04005	0.07218
HB16	0.01154	0.03667	0.04705	0.07788
Mean	0.012	0.035	0.048	0.070
S.D= ±	0.0008	0.0041	0.0047	0.0073

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Fig,1 A plot between Volume flow rate on x-axis coefficient of viscosity on y-axis for water.

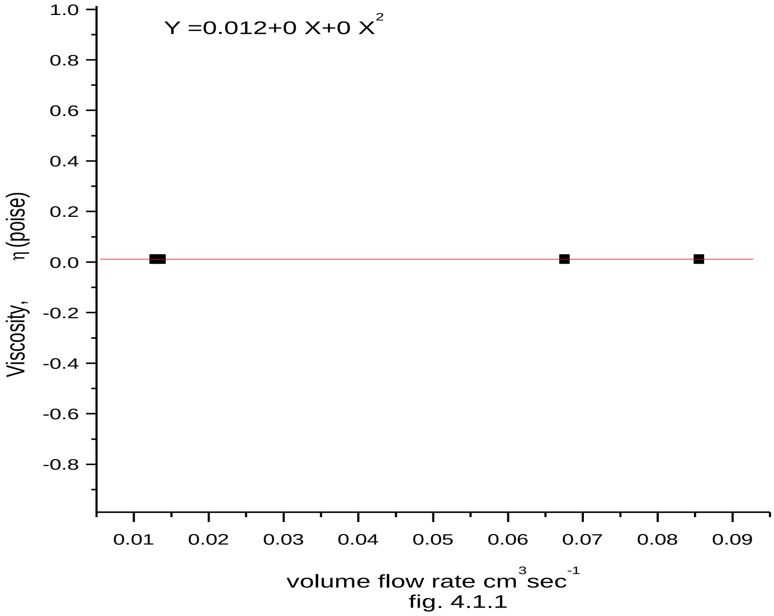


fig. 4.1.1

Fig.2 A plot between volume flow rate on x-axis and coefficient of viscosity on y-axis for human blood

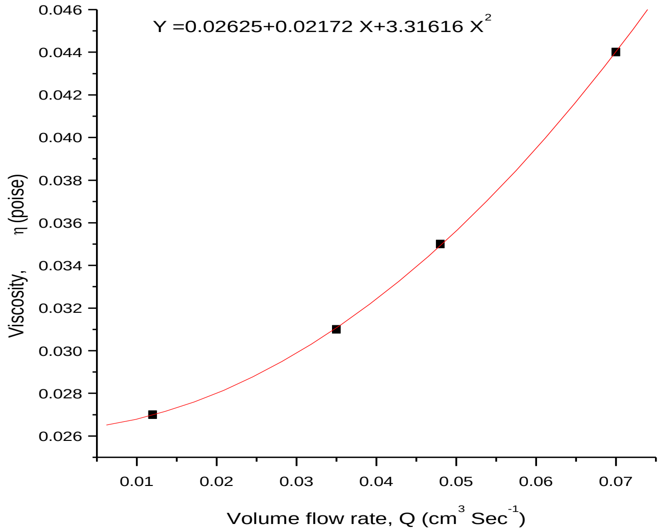


fig. 4.1.2

Fig.3: A plot between Radius-R(Cm) on X-Axis and coefficient of viscosity on y-axis for water.

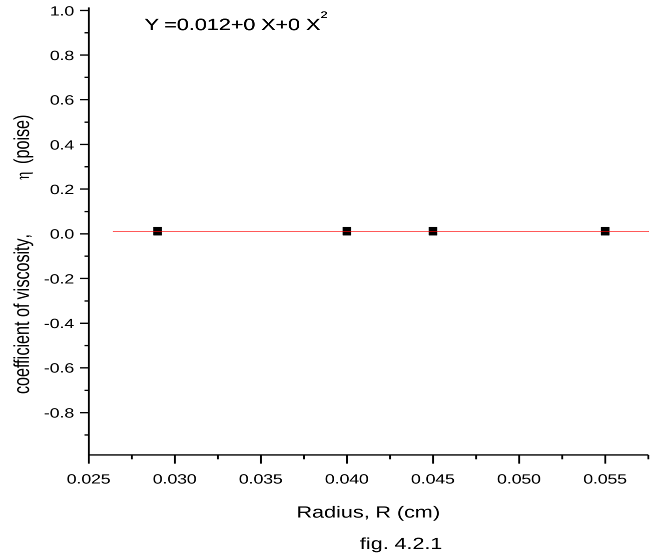
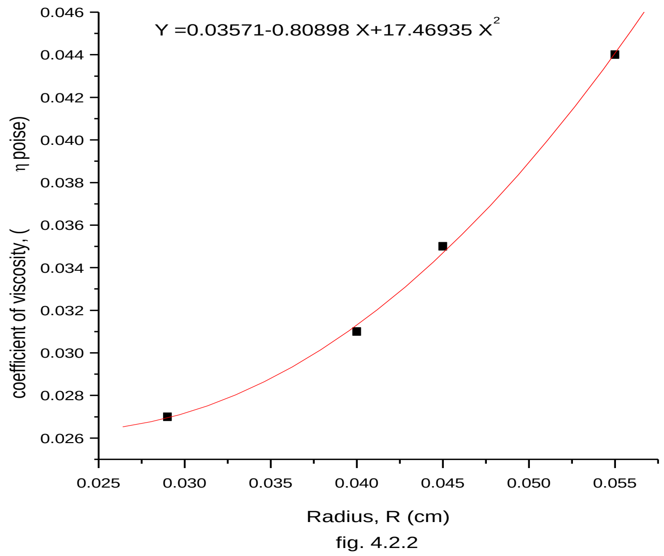


Fig.4: A plot between Radius on x-axis and Coefficient of viscosity on y-axis for human blood.



FINDINGS:

In this study, it is observed that the coefficient of viscosity of blood increases nonlinearly with increase of radius of capillary tube (Tables 4). However, in the case of water, the coefficient of viscosity remains constant (Table 3). As it is known, in Newtonian fluids the viscosity is independent of resistance and the stress, strain relation is linear (Fig.1), where as in a non-Newtonian fluids viscosity increases non linearly with the radius of a capillary tube. The volume flow rate of blood also increases with the increase of radius (Table 6). It is interesting to know that the coefficient of viscosity and volume flow rate both are proportionally increasing with the radius. In other words, it can be stated that the coefficient of viscosity increases as the flow rate increases. But this is not true in the case of Newtonian fluids. Hence, it can be stated that the viscosity increases with the increase of radius of the tube (blood vessel).

It was observed that in very small diameter tubes the apparent viscosity of blood has a very low value. The viscosity increases with the increase in tube diameter. This phenomenon is referred to as the Fahraeus-Lindqvist effect, which says that the apparent viscosity of blood is a function of tube diameter.

CONCLUSIONS

- For Newtonian liquids like water, the viscosity is independent of variations in the diameter of capillary tube, and thus the viscosity is constant.
- Moreover, is seen from this study that for non-Newtonian fluids like blood, the viscosity is a function of radius of the tube.
- Viscosity is affected by various factors. It depends on the amount of plasma proteins, the number and the volume of corpuscles.
- However, there are many factors that individually affect the viscosity, but high blood viscosity invariably accompanies degenerative diseases. Because high blood viscosity always leads to a slow down of circulation and reduces oxygenation of tissues. Therefore variations in the viscosity of blood definitely, have the adverse effects on the human beings.

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