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Mathematical modeling of two phase human pulmonary blood flow in arterioles: Lung cancer

Dheerendra Kumar, V Upadhyay and SK Chaturvedi

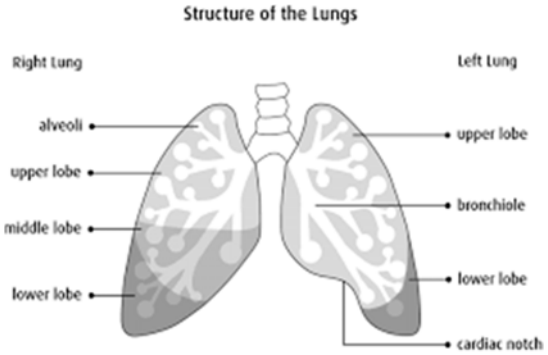
Abstract
Present paper envisage a model of two phased blood flow keeping in view the nature of Pulmonary blood circulation in human body, human Pulmonary arterioles remote from the heart and proximate to the Lung. The viscosity increases in the arterioles due to formation of rouleaux along axis of red blood cells. We have applied the Herschel Bulkley Non-Newtonian model in Bio- fluid mechanical setup with the help of clinical data in case of Lung Cancer for hemoglobin versus blood pressure. The overall presentation is in tensorial form and the solution technique adopted is analytical as well as numerical. The role of hematocrit is explicit in the determination of blood pressure drop in case of pulmonary disease Lung Cancer the graphical presentation for particular parametric value is much close to the clinical observation.

Keywords: Lung cancer, pulmonary blood flow, hematocrit, Herschel Bulkley Non-Newtonian model etc

1. Introduction

1.1 Structure and function of the Lung

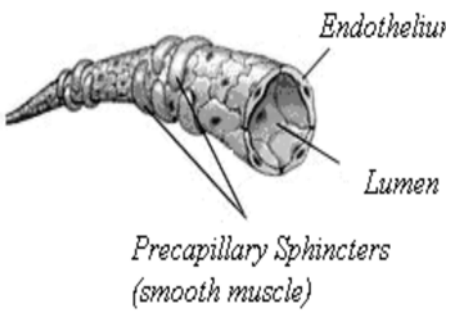
The human lungs are divided into lobes. The right lung has three lobes (upper, middle, lower) and the left lung has two lobes (upper and lower). The lung can be rather naturally grouped into a number of almost distinct sub-topics: gas exchange, neural control, mechanics, and non-respiratory functions related mostly to defense (Jason H. and T. Bates, 2009) [8]. The lung is an elastic structure that collapses like a balloon and expels all its air through the trachea whenever there is no force to keep it inflated. Also, there are no attachments between the lung and the walls of the chest cage, except where it is suspended at its hilum from the mediastinum. Instead, the lung "floats" in the thoracic cavity, surrounded by a thin layer of pleural fluid that lubricates movement of the lungs within the cavity. Further, continual suction of excess fluid into lymphatic channels maintains a slight suction between the visceral surface of the lung pleura and the parietal pleural surface of the thoracic cavity. Therefore, the lungs are held to the thoracic wall as if glued there, except that they are well lubricated and can slide freely as the chest expands and contracts (Guyton and Hall, 2006) [6]. The normal weight range of each lung in an adult is roughly 300 to 450 g. Increased lung weight is an indication of congestion, edema, or inflammatory exudates. Lung volume, measured in the inflated state by water displacement, ranges from 3.5 to 8.5 L for both lungs. The lung is covered by a smooth glistening visceral pleura. The pleural membrane is translucent, but as it rests on the lung, the visceral pleural surface appears pink. The visceral pleura wraps around the lung and is reflected from the meditational pleura at the hilum and pulmonary ligament. Prominent pleural indentations include, on the right, grooves for the esophagus and supe. (Joseph F. *et. al.,* 2009) [9].



1.2 Functions of the Pulmonary Arterioles

Arterioles are the smallest vessels of the arterial system, with a diameter of about 1/3 millimeter or smaller. They serve as the major determinant of blood pressure and blood flow to the individual organs. Arterioles have a much smaller diameter then arteries and thus provide significant resistance to the flow of blood. This resistance creates pressure in circulatory system. Pressure is required to provide adequate flow of blood to all parts of the body. Blood flow to individual organs can be regulated by controlling the diameter of the arterioles. Vasodilatation (the term vasodilation refers to the dilation or relaxation of the arterioles to allow more blood to an area) of an arteriole lowers the resistance and results in an increase in flow through that particular arterioles. (Varun Mohan *et al*., 2012) [20]. Arterioles are the blood vessels in the arterial side of the vascular tree that are located proximal to the capillaries and, in conjunction with the terminal arteries, provide the majority of resistance to blood flow. Consequently, arterioles are important contributors to the regulation of mean arterial pressure and tissue perfusion. Their wall consists of cellular and extracellular components that have been traditionally classified as conforming three layers: an intima containing endothelial cells sited on a basement membrane; a media made of an internal elastic lamina apposed by one or two layers of smooth muscle; and an adventitia composed mostly of collagen bundles, nerve endings and some fibroblasts. These components of the arteriolar wall are dynamically interconnected, providing a level of plasticity to the arteriolar wall that blurs the traditional boundaries of a rigid layered classification (Luis A. Martinez - Lemus, 2011) [11].

We have visualize mathematical modeling with the help of two phase Herschal Bulkley Non Newtonian model we explain the blood flow in various arterioles in the human heart. But present work will focus on pulmonary circulatory system, pulmonary circulatory system is a sub system of whole circulatory system, (Srivastava Manoj *et al*., 2012) [17]. On the basis of previous work in present study be achieve new findings which are discussed separately below.

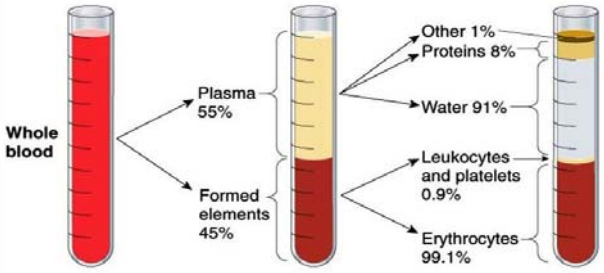


1.3 Constitution of Blood

Blood is the "the river of life" that surges within us. It transport everything that must be carried from one place to another within the body; nutrients, wastes, and body heat, through blood vessels (Zainab H. Al - Zubaydi). Blood is a circulating tissue composed of fluid plasma and cells (red blood cells, white blood cells, platelets). Anatomically, blood is considered a connective tissue, due to its origin in the bones and its function. Blood is the means and transport system of the body used in carrying elements (e.g. nutrition, waste, heat) from one location in the body to another, by way of blood vessels. Blood is made of two parts:

1. Plasma which makes up 55% of blood volume.
2. Formed cellular elements (red and white blood cells, and platelets) which combine to make the remaining 45% of blood volume (Human Physiology/Blood physiology).

The human blood approximately 40 to 45% by volume of the normal human blood and more than 99% of all blood cells. The first percentage is called hematocrit. Thrombocytes are a vital component of the blood clotting mechanism. The total volume concentration of leukocytes and thrombocytes is only about 1% (N. Bessonov *et al.,* 2016) [13]. Then we have considered only two phases of blood. Which is one of red blood cells and other phase is plasma.



1.4 Description of Lung Cancer

Cancer is a complex disease that forms and progresses through multiple processes and phases. These processes include sustained tumor growth, metastasis, angiogenesis, and immune response. The complexity of these processes and the involvement of multiple spatial and temporal scales, from the molecular (e.g., genetic and epigenetic alterations, receptor-ligand interactions), to signaling networks, to cellular level (e.g., enhanced proliferation, migration and invasion, epithelial-mesenchymal transition), to tumor/tissue level (e.g., tumor heterogeneity, tumor microenvironment), to whole organism (e.g., circulated tumor cells, mechanistic pharmacokinetics), (Kerri-Ann Norton *et al*., 2015) [10]**.** Lung cancer has the largest proportion of cases caused by smoking: According to a recent estimate, in the UK about 85% of lung cancer cases in men are attributable to smoking (excluding environmental tobacco smoke) and about 80% of cases in women. Because of its poor prognosis, lung cancer is still the most common cause of cancer death in both men and women, responsible for more than 1 in 5 of all cancer deaths in the UK. Fewer than ten per cent of people with lung cancer will survive at least five years beyond diagnosis, (Smoking and Cancer, 2015) [1].

2. Real Model

2.1 Choice of frame of reference

We have to selected a frame of reference for mathematical modeling of the state of a moving blood· keeping in view

the difficulty and generality of the problem of blood flow, we select generalized three-dimensional orthogonal curvilinear co-ordinate system, briefly prescribed as E3, called as 3-dim Euclidean space, We interpret the quantities related to blood flow in tensorial form which is comparatively more realistic, The biophysical laws thus expressed fully hold good in any co-ordinate system, which is compulsion for the truthfulness of the law (Mishra *et al.*, 1965) [12].

Now, let the co-ordinate axes be OX_i, O denotes origin and superscript i= 1,2,3 let Xi be the co-ordinates of any point P in space, The mathematical description of the state if a moving blood is affected by means of functions which give the distribution of the blood velocity vk = vk(X_i, t), k= 1,2,3 and of any two thermodynamic quantities pertaining to the blood, for instance the pressure p = p (X_i, t) and the density ρ = ρ (X_i, t), As is well known, all the thermodynamic quantities are determined by the values of any two of them, together with the equate of state, Hence, if we are given five quantities, namely the three components of velocity vk, the pressure p and the density ρ, the state of moving blood is completely determined· All these quantities are, in general, functions of the co-ordinates X_i, i=1,2,3 and of the time t, We emphasize that Vk (X_i, t) is the velocity of the blood at a given point X_i in space and at a given t, *ie* it refers to fixed points in space and not to fixed particles of the blood; in the course of time, the latter move about in space, The same remarks apply to p and ρ Blood is a mixed fluid, (Chandra, H. *et al.,* 2014) [3].

The first phase is red blood cells, and other phase is plasma, while the other phaseis that of blood cells· The blood cells are enclosed with a semi-permeable membrane whose density is greater than that of plasma, these blood cells are uniformly distributed in plasma, Thus blood can be considered as a homogeneous mixture of two-phases (Sherman *et al.* 1989) [15].

2.2 Choice of parameters

Blood is the Non- Newtonian fluids, then using this constitutive equation for fluids.

$$\tau = \eta e^n$$

If $n = 1$ then the nature of fluid is Newtonian and if $n \neq 1$ then the nature of fluid is Non-Newtonian fluids.Where, τ is denoted by stress,e is denoted by strain rate this constitutive equation is called Herschel - Bulkily Non Newtonian law, and n is denoted by the parameter, these equation uses equation of motion. In present study there are five parameter are used but three parameter are frequently used namely velocity, pressure P and densityρ. (manoj Srivastav *et al.*, 2012) [17].

2.3 Choice of constitutive equation:

We have using in two phase blood flow through arterioles and whose constitutive equation is as follows-

$$T' = \eta_m e^n + T_p\left(T' \geq T_p\right)$$

where, $T_p$is the yield stress.

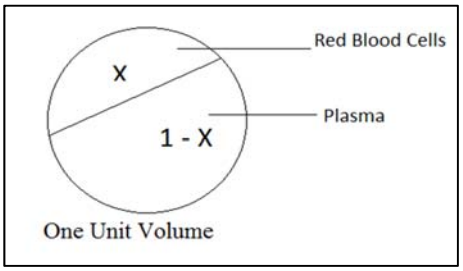
When strain rate $e = 0$ ($T' < T_p$) a core region is formed which flows just like a plug (Upadhyay, 2000) [19].

2.4 Constitution of two phase blood volume

They are already conceder two-phases in blood, (Trivedi Neha *et al.,* 2013) [18]. The flow of blood is affected by the presence of blood cells. This effect is directly proportional to the volume occupied by blood cells.

Let the volume portion covered by blood cells in unit volume be X, X is replaced by H */100*, where H is the Hematocrit the volume percentage of blood cells. Then the volume portion covered by the plasma will be (*1-X*). If mass ratio of cells to plasma is r then clearly:$r = \frac{X\rho_c}{(1-X)\rho_p}$.

Where ρ_c and ρ_p are densities of blood cells and plasma respectivily. Usually this mass ratio is not a constant. Even then this may be supposed to constant in present context.



3. Mathematical Model / Formulation

We have recommended that blood flow in vessels is a peristaltic transport system because they thought blood is having two layers of fluid while in the peripheral reasons of vessels blood flow is a Newtonian phenomenon. Blood is in the liquid form and it is non-Newtonian. Though blood is not an ideal fluid, even to develop the equation of motion.(Singh and Pandey, 1986), we start with a model of ideal fluid. The second important principle of fluid dynamics is that of conservation of momentum. The equation of motion is based on this principle. According to this principle, the total momentum of any fluid system is conserved in absence of external force.

$$\frac{dp}{dt} + P - F_{v(viscosity)} = 0\ (External\ Foorce)$$

The blood can be considered as homogeneous mixtures of two phases. We derive the fundamental equation of continuity, which is a mathematical expression of principal of conservation of matter.

3.1 Equation of Continuity

If mass ratio of cells to plasma is r then clearly:

$$r = \frac{X\rho_c}{(1-X)\rho_p} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.1)$$

Where ρ_c and ρ_p are densities of blood cells and plasma respectivily. Usually this mass ratio is not a constant. Even then this may be supposed to constant in present context.

The both phase of blood, i.e. blood cells and plasma move with the common velocity. Campbell and Pitcher have presented a model for this situation. Giving to this model, we consider the two phase of blood separately.

The principles of conservation of mass in arterioles of pulmonary circulatory system, equation of continuity for two phases are following as

$$\frac{\partial(X\rho_c)}{\partial t} + (X\rho_c V^i)_{,i} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.2)$$

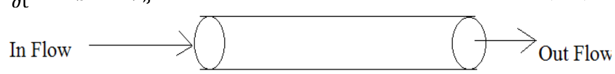
$$\frac{\partial(1-X)\rho_p}{\partial t} + (1-X)\rho_c V^i)_{,j} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (3.3)$$

Where V is the common velocity of two phase blood cells and plasma. If we define the uniform density of blood ρ_m as follows:

$$\frac{1+r}{\rho_m} = \frac{r}{\rho_c} + \frac{1}{\rho_p} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Then equation (3.2) and (3.3) can be combined together as:

$$\frac{\partial \rho_m}{\partial t} + (\rho_m V^i)_{,j} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$



Artrieols Flow

3.2 Equation of motion for blood-flow

The hydro dynamical pressure P between the two phases of blood can be supposed to be uniform because the both phases i.e. blood cells and plasma is always in equilibrium state in blood. Taking viscosity coefficient of blood cells to be η_c and applying the principle of conservation of momentum in pulmonary circulatory system, we get the equation of motion for the phase of blood cells as follows:

$$X_{\rho_c} \frac{\partial V^i}{\partial t} + \left(X_{\rho_c} V^j\right) V^i, j = -X_p, j\, g^{ij} + X\eta_c \left(g^{jk} V^i, k\right), j \ldots (3.6)$$

Similarly, taking the viscosity coefficients of plasma to be equation of motion for plasma will be as fallows-

$$(1-X)_{\rho_c} \frac{\partial V^i}{\partial t} + \{(1-X)_{\rho_c} V^j\} V^i, j = -(1-X)_p, j\, g^{ij} + (1-X)\eta_c \left(g^{jk} V^i, k\right), j \ldots\ldots (3.7)$$

Now adding equation (3.6) and (3.7) and using relation (3.4), the equation of motion for blood flow with the both phases will be as fallows-

$$\rho_m \frac{\partial V^i}{\partial t} + (\rho_m V^i) V^i, j = -P, j + \eta_m \left(g^{jk} V^i, k\right), j \ldots \ (3.8)$$

Where $\eta_m = X\eta_c + (1-X)\eta_p$ are the viscosity coefficients of blood as a mixture of two phase. In this satuation, the blood cell line up on the axis to build up rolex. Hence a yield stress is produced. Though this yield stress is very small, even then the viscosity of blood is increased nearly ten times.

The Herschel Bulkley low holds good on the two phase blood flow through arterioles and whose constitutive equation is as fallows-$T' = \eta_m e^n + T_p \left(T' \geq T_p\right)$.where, T_p is the yield stress.

When strain rate $e = 0\ (T' < T_p)$ a core region is formed which flows just like a plug. Let the radius of the plug be r_p. The stress action on the surface of plug will be T_p. Equating the forces acting on the plug, we get,

Whose generalizes from will be as follows-

$$T^{ij} = -Pg^{ij} + T_e^{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.9)$$

Where $\quad T^{ij} = \eta_m (e^{ij})^n$

While $\quad e^{ij} = (g^{jk} V^i_{,k} + g^{ik} V^j_{,k})$

Where the symbols have their usual meanings.

Now we consider the basic equation for Non Newtonian Herschel-Buckley flow as follows.

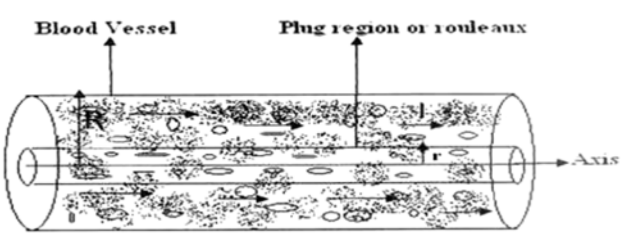


Fig 3: Herschel Bulkley blood flow

3.3 Equation of Continuity-

$$\frac{1}{\sqrt{g\sqrt{(gV^i)_{,i}}}} = 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

3.4 Equation of Motion-

$$\rho_m \frac{\partial V^i}{\partial t} + \rho_m V^j V^i, j = -T^{ij} e, j$$

Where all the symbols have their usual meaning.

4. Analysis

Since, the blood vessels are cylindrical; the above governing equations have to be transformed into cylindrical co-ordinates. As we know earlier: $X^1 = r, X^2 = \theta,\ X^3 = z$.

Matrix of metric tensor in cylindrical co-ordinates is as follows-

$$[g^{ij}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & r^2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

While matrix of conjugate metric tensor is as follows-

$$[g_{ij}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1/r^2 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Where the Christoffel's symbols of 2^{nd} kind as follows-

$\left\{ {1 \atop 2\ \ 2} \right\} = -r$, $\left\{ {1 \atop 2\ \ 2} \right\} = \left\{ {1 \atop 2\ \ 2} \right\} = \frac{1}{r}$ remaining others are zero.

Relation between contra variant and physical components of velocity of blood flow will be as follows-

$\sqrt{g^{11}v^1} = v_r \Rightarrow v_r = v^1$, $\sqrt{g^{22}v^2} = v_\theta \Rightarrow v_\theta = rv^2$, $\sqrt{g^{33}v^3} = v_z \Rightarrow v_z = v^3$,

again the physical components of $p_{,j}g^{ij}$ are $\sqrt{g_{ij}}p_{,j}g^{ij}$

Now, equation 9 and 10 are transformed into cylindrical from so as to solve as power low to get

Equation of continuity:

$$\frac{\partial V}{\partial Z} = o$$

The equation of motion-

r-component: $-\frac{\partial p}{\partial z} = 0, \emptyset - \text{component: } 0 = 0$

z-component: $0 = -\frac{\partial p}{\partial z} + \frac{\eta_m}{r}\left[r\left(\frac{\partial V_z}{\partial r}\right)^n\right]$

Here, this fact has been taken in view that the blood flow the axially symmetric in arteries concerned, i.e. $V_\theta = 0$ and $V_r, V_z and p = p(z) and$

$$0 = -\frac{\partial p}{\partial z} + \frac{\eta_m}{r}\left[r\left(\frac{\partial V_z}{\partial r}\right)^n\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.1)$$

Since, pressure gradient $-\frac{dp}{dz} = P$

$r\left(\frac{dV}{dZ}\right)^n = -\frac{Pr^2}{2\eta_m} + A$, we apply boundary condition at $r = 0. V = V_0$ than $A = 0$.

$\Rightarrow -\frac{dv}{dr} = \left(\frac{Pr}{2\eta_m}\right)^{\frac{1}{n}}$Replace from $r - r_p$

$$-\frac{dv}{dr} = \left(\frac{\frac{1}{2}pr - \frac{1}{2}p_r}{\eta_m}\right)^{\frac{1}{n}} \Rightarrow \frac{dv}{dr} = -\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}(r - r_p)^{\frac{1}{n}} \ldots\ldots\ldots (4.2)$$

Integrating above equation (4.2) under the no slip boundary condition $V = 0$ at $r = R$ so we get:

$$V = \left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}\frac{n}{n+1}\left[(R - r_p)^{\frac{1}{n}+1} - (r - r_p)^{\frac{1}{n}+1}\right] \ldots\ldots\ldots (4.3)$$

This is the formula for velocity of blood flow in arterioles. Putting $r = r_p$ to get the velocity v_p of plug flow as follows:

$$v_P = \frac{n}{n+1}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}(R - r_p)^{\frac{1}{n}+1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

Where the value of r_p is taken form (3.7).

5. Result and Discussion

Examination: Hematocrit v/s blood pressure in during Lung Cancer patient.

Patient name: Mr. Susheel Kumar Toppo

Age: 27 years

Diagnosis: Lung cancer (Pulmonary disease)

Date	HB(Hemoglobin)	Hematocrit ($3 \times HB$)	Blood Pressure (BP)	Arterioles Pressure D $\frac{\left(\frac{S+D}{2}\right)+D}{3} - \frac{S+D}{2}$
16/06/2014	10.33	30.99	130/70	-43.333
22/10/2014	10.0	30.0	90/60	-30.00
13/08/2015	9.26	27.78	130/90	-43.3333
19/02/2016	8.0	24.0	100/60	-33.333
20/08/2016	6.8	20.4	90/60	-30.00

The flow two phased blood flow in arterioles is-

$$Q = \int_0^{r_p} 2\pi r v_p + \int_{r_p}^{R} 2\pi r v dr$$

$$= \int_0^{r_p} 2\pi r \frac{n}{n+1}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}(R - r_p)^{\frac{1}{n}+1} dr + \int_0^{r_p} 2\pi r \frac{n}{n+1}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}\left[(R - r_p)^{\frac{1}{n}+1} - (R - r_p)^{\frac{1}{n}+1}\right] dr$$

Using (4.2) and (4.4), we get

$$Q = \frac{2\pi n}{(n+1)}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}}(R - r_p)^{\frac{1}{n}+1}\left[\frac{r^2}{2}\right]_0^{r_p} + \frac{2\pi n}{(n+1)}\left(\frac{p}{2\eta_m}\right)^{\frac{1}{n}}\left[\frac{r^2}{2}(R - r_p)^{\frac{1}{n}+1} - \frac{r(r - r_p)^{\frac{1}{n}}}{\frac{1}{n}+1} + \frac{(r - r_p)^{\frac{1}{n}+3}}{\left(\frac{1}{n}+1\right)\left(\frac{1}{n}+3\right)}\right]_{r_p}^{R}$$

$$Q = \frac{2\pi n}{(n+1)}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}} r_p^2(R - r_p)^{\frac{1}{n}+1} + R^2(R - r_p)^{\frac{1}{n}+1} - \frac{2R(R - r_p)^{\frac{1}{n}+2}}{\left(\frac{1}{n}+2\right)} + \frac{2R(R - r_p)^{\frac{1}{n}+3}}{\left(\frac{1}{n}+2\right)\left(\frac{1}{n}+3\right)} - r_p^2(R - r_p)^{\frac{1}{n}+1}$$

$$Q = \frac{\pi n}{(n+1)}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}} R^{\frac{1}{n}+3}\left[\frac{{r_p}^2}{r^2}\left(1 - \frac{{r_p}^2}{R}\right)^{\frac{1}{n}+1} + \left(1 + \frac{r_p}{R}\right)^{\frac{1}{n}+1}\left(1 - \frac{r_p}{R}\right)^{\frac{1}{n}+2} - \frac{2\left(1 - \frac{r_p}{R}\right)^{\frac{1}{n}+2}}{\left(\frac{1}{n}+2\right)} + \frac{2\left(1 - \frac{r_p}{R}\right)^{\frac{1}{n}+3}}{\left(\frac{1}{n}+2\right)\left(\frac{1}{n}+3\right)}\right] \ldots\ldots\ldots\ldots\ldots\ldots (5.1)$$

P = Pressure gradient,
v = Viscosity of mixture (Blood),
n = Parameter

Now we have, $Q = 425 \frac{ml}{min}$,

$Q = 0.00708333\ m^3/second$

$R = 1, r_p = \frac{1}{3}$,

According to Gustafson, Daniel R. (1980) [5]

$\eta_p = 0.0013$ pascal second

According to Glenn Elert (2010) [4]

$\eta_m = 0.027$ pascal second

Arterioles Pressure Drop $(P_f - P_i)_{Systolic} = 3993.96$ Pascal-second

and $H = 30.0$

Pulmonary arterioles length = 0.05 m^3 (5 cm)
By using relation$\eta_m = \eta_c X + \eta_p (1 - X)$
Where, $X = \frac{H}{100}$, we get η_c
$\eta_m = \eta_c X + \eta_p (1 - X)$
$\eta_m = \eta_c X + \eta_p (1 - X)$
$\eta_m = 0.000873H + 0.00091$
Now, Substituting the values of $r_p$and R in Equation (5.1)-

$$Q = \frac{\pi n}{(n+1)}\left(\frac{P}{2\eta_m}\right)^{\frac{1}{n}} R^{\frac{1}{n}+3}\left[\frac{{r_p}^2}{r^2}\left(1-\frac{{r_p}^2}{R}\right)^{\frac{1}{n}+1} + \left(1+\frac{r_p}{R}\right)^{\frac{1}{n}+1}\left(1-\frac{r_p}{R}\right)^{\frac{1}{n}+2} - \frac{2\left(1-\frac{r_p}{R}\right)^{\frac{1}{n}+2}}{\left(\frac{1}{n}+2\right)} + \frac{2\left(1-\frac{r_p}{R}\right)^{\frac{1}{n}+3}}{\left(\frac{1}{n}+2\right)\left(\frac{1}{n}+3\right)}\right]$$

And we get equation-

$$Q = \pi\left(\frac{2P}{6\eta_m}\right)^{\frac{1}{n}}\left(\frac{2}{27}\right)\left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right]$$

Or, $\frac{27\times Q}{2\pi} = \left(\frac{P}{3\eta_m}\right)^{\frac{1}{n}}\left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right]$

Let $A = \left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right]$

$\Rightarrow \frac{P}{3\eta_m} = \left(\frac{27\times Q}{2\pi A}\right)^n$

$\Rightarrow P = \left(\frac{27\times Q}{2\pi A}\right)^n . 3\eta_m$

$P = -\frac{dp}{dz}$

$-dp = Pdz$

And limit from the pressure from Z_f to Z_i then-

$$\int_{P_f}^{P_i} dP = -\int_{Z_f}^{Z_i}\left(\frac{27\times Q}{2\pi A}\right)^n . 3\eta_m dz$$

Where $P_f - P_i$ = pressure drop and
$Z_f - Z_i$ = pulmonary artriols length.

$P_f - P_i = \left(\frac{27\times Q}{2\pi A}\right)^n . 3\eta_m . (Z_f - Z_i)$

Or, $\frac{27\times Q}{2\pi A} = \left(\frac{P_f - P_i}{(Z_f - Z_i)\,3\eta_m}\right)^{1/n}$

$\frac{27\times Q}{2\pi} = \left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right]\left(\frac{P_f - P_i}{(Z_f - Z_i)\,3\eta_m}\right)^{1/n}$

$0.0271 = \eta_c(0.3) + 0.0013(0.7)$
$\eta_c = 0.0873$ Pascal second
Again using this relation and change in to the hematocrit-

Substituting the value of $Q, \eta_m, (P_f - P_i) and (Z_f - Z_i)$ and solve by numerical methods

$\frac{27\times 0.0070833}{6.28} = \left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right]\left(\frac{3993.96}{0.05\times 0.081}\right)^{1/n}$

$0.03045669 = \left[\frac{26n^3+33n^2+9n}{6n^3+11n^2+6n+1}\right](986903.704)^{1/n}$

And we get $n = -2.881$

Now again using equation

$P_f - P_i = \left(\frac{27\times Q}{2\pi A}\right)^n . 3\eta_m . (Z_f - Z_i)$

$\Delta P = \left(\frac{27\times Q}{2\pi A}\right)^n . 3\eta_m . (Z_f - Z_i)$

$= \left(\frac{27\times 0.007084}{6.28\times 3.670637}\right)^{-2.881} \times 3\eta_m \times (0.05)$

$= (989760.9) \times (0.05) \times 3\eta_m$

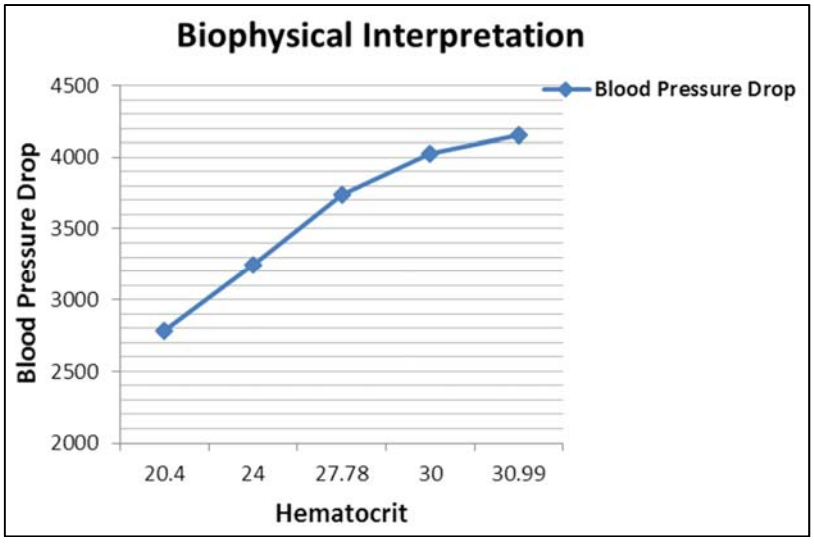
$= 148464.135(\,0.000873H + 0.00091)$

$= 129.60919H + 135.102363$

$\Delta P = 129.60919H + 135.102363$

H (Hematocrit)	30.99	30.0	27.78	24.0	20.4
BP(Blood Pressure drop)	4151.6 9116	4023.3 7806	3735.6 4566	3245.7 2292	2779.1 2984

6. Biophysical Interpretation (Graphical presentation of Clinical Data)



7. Conclusion

A simple study of the graph 20.4 to 27.78 linear and 27.78 to above graph upper convex between blood pressure drop and hematocrit in suffering lung cancer patient and confirmations that when hematocrit increase then blood pressure drop also increased and shows a non-linier graph. That is hematocrit inversely proportional to blood pressure drop.

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