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CREATING APPLICATION OF MATHEMATICAL MODELLING OF OXYGEN AND NUTRIENT MOVEMENT IN BLOOD ARTERIES

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ABSTRACT

The mathematical modeling of the oxygen and nutrient transportation in blood arteries C_{blood} (x,t) is investigated in this study and creating program by using Python and Google Colab for observing. Developing a mathematical model that explains blood flow and the diffusion of oxygen and nutrients over the walls of blood arteries in tissues takes front stage. The model considers the physical characteristics of the circulatory system as well as their interaction with the body's tissues: pressure, blood flow velocity, concentrations of oxygen O (x,t) and nutrients N(x,t). The primary objective of the effort is to construct an efficient model that will improve the knowledge of hemodynamic processes and support the evolution of techniques for cardiovascular disease diagnosis and treatment. Many cardiovascular and systemic disorders may be linked to hampered oxygen and nutrient movement in blood vessels. Often involving disturbed blood flow, limited oxygen availability to tissues, or poor nutrient diffusion, these disorders cause major health problems. Some important diseases connected to such disabilities are: Atherosclerosis, Ischemic Heart Disease (Coronary Artery Disease), Peripheral Artery Disease (PAD), Diabetes Mellitus, Chronic Obstructive Pulmonary Disease (COPD), Heart Failure, Anemia, Septic Shock, Vascular Dementia.

INTRODUCTION

Many biological and medical elements support the importance of replicating the mechanisms in charge of oxygen and nutrition transport in blood vessels. In the area of diagnosing, treating, and projecting the results of many different medical problems, the creation and enhancement of mathematical models that relate to the blood circulation and metabolism of the human body is of enormous relevance. In this given research work by Perdikaris, Paris, and George Em Karniadakis about topic "Fractional-order viscoelasticity in one-dimensional blood flow models." Annals of biomedical engineering 42 (2014): 1012-

1023.da fractional order viscoelasticity models have been used for accurate description of blood flow behavior [1,2,3,4,5,6,7]. Often, many conventional models employ ordinary differential equations with integer values that failed to capture the complex and variable response exhibited in realistic tissues. The researchers observed to develop and to improve one-dimensional flow models with the viscoelastic properties of blood in by counting fractional calculus. Researchers Zhao, T. Y., Johnson, E. M., Elisha, G., Halder, S., Smith, B. C., Allen, B. D., & Patankar, N. A. (2023) Blood–wall fluttering instability as a physiomarker of the progression of thoracic aortic aneurysms. Nature Biomedical Engineering, 7(12), 1614-1626 in this study examines blood-wall fluttering instability in thoracic aortic aneurysms. The authors propose that this instability might be a physiomarker to ignore the development of TAAs, fundamental diseases capable of becoming life-threatening complications. The research acknowledges the manner in which pulsatile blood flow and the elastic characteristics of the aortic wall may produce fluttering instability—defined by oscillations inside the wall of the aorta. The authors suggest that the characteristics and existence of blood-wall fluttering instability could indicate the progress of TAAs. Analyzing these instabilities might provide doctors the instruments they need to evaluate the degree of an aneurysm rupture risk [1,2,3,4,5,6,7]. Experimental and Computational Approaches: To understand the physics of fluttering instability, this work combines computational fluid dynamics simulations with experimental data. The method that combines many domains strengthens the results. Implications for Monitoring: The ability to identify fluttering instability may provide a non-invasive approach for monitoring patients with TAAs, hence improving risk classification and treatment planning. An growth in the aorta that persists within the chest cavity, thoracic aortic aneurysms (TAAs) may cause significant issues should they rupture. Controlling patients precisely depends on constant evaluation of their development. Possibly reflecting structural changes in the artery, fluttering instability is a dynamic phenomenon in which the aorta wall wavers because to its interaction with pulsatile blood flow. Particularly the sound structure and stability of the aorta, physiomarker is a biological feature that is measured to depict a physiological state [1,2,3,4,5,6,7].

Alastruey, J., Charlton, P. H., Bikia, V., Paliakaite, B., Hametner, B., Bruno, R. M., & Westerhof, B. E. (2023) examines about arterial pulse wave modeling and analysis for vascular aging studies: a review from VascAgeNet American Journal of Physiology-Heart and Circulatory Physiology, 325(1), H1-H29. The state-of- the-art methods in arterial pulse wave modeling and analysis were noted in this review paper, along with their use in determining vascular age, a biomarketer for evaluating cardiovascular risk. Emphasizing their usage in clinical and research environments, the researchers provide a thorough summary of the techniques and tools used to model and analyze pulse wave data [1,2,3,4,5,6,7].

Many elements highlight the topic and the present concerns as well as the relevant issues:

• Medical Importance Circulatory disorders: Nutrient and oxygen flow is substantially influenced by circulatory disorders including coronary heart disease, atherosclerosis, and hypertension. Mathematical models depicting the mechanics of transportation in blood vessels might be of use to medical practitioners in helping them forecast and stop the emergence of certain diseases. Severe consequences include cell and tissue death follow from lower oxygenation of tissues. Development of therapy options for disorders connected to oxygen deprivation, such as strokes and heart attacks, depends much on modeling.

- Two challenges to reaching modeling accuracy: There is no denying the intricacy of physiological systems. In the real world, many factors affect the distribution of oxygen and nutrients: vascular geometry, blood viscosity, blood flow velocity, tissue metabolism, and so on. Developing a trustworthy model calls for particular attention to these elements, which challenges one. Individual differences in geometry of blood vessels, wall elasticity, blood composition, and tissue metabolic activity occur among individuals. Models must have these specific elements if they are to fairly represent physiological processes in various individuals.
- Three negative aspects of present approaches: Many times lacking accuracy and prone to mistakes, the clinical data required for model validation makes correct modeling of difficult systems, like the cardiovascular system difficult. Sometimes complex mathematical models have simplifications, including the assumption of continuous blood flow or the reduction of vascular architecture, which might undermine the accuracy and reliability of the outcomes.
- Desire for fresh concepts: Personalized medicine is becoming more and more important as treatment approaches modernly evolve. Customized models that include unique physiological characteristics of each patients might help to make creative diagnosis and treatment strategies feasible. Medical modeling aids to enhance the real-time prediction and analysis of complicated processes by means of machine learning and artificial intelligence inclusion. Combining artificial intelligence with conventional mathematical modeling techniques increases the opportunity to better understand blood circulation and chemical transport.
- Poor understanding of microcirculation: Though the mechanics of large arteries are well-understood, little is known about the flow of oxygen and nutrients via micro vessels and capillaries. Lack of unknown places. Verification and calibration of models depend on exact data on metabolism, blood flow, and other physiological factors, which is insufficient empirical evidence. The lack of enough data limits the development of models. Building thorough simulations of the circulatory system calls very significant computer resources. Developing models meant for use in clinical settings or for large patient groups might provide a problem based on this.

The essential mechanism for the operation of cells and organs is the movement of oxygen and nutrients—especially glucose—through blood vessels. This mechanism guarantees oxygen delivery to tissues and cells while nutrients are absorbed and used for energy generation by means of various important physiological phases. Using a flowchart depicting the complex interactions among blood components, oxygen, and nutrients in the capillaries and tissues of the body, the following article investigates a mathematical model of these processes. Blood arteries mostly serve to move oxygen from the lungs to the tissues where it is required. Oxygen hooks itself to hemoglobin, a protein seen in red blood cells in this process. Hemoglobin binds oxygen molecules and transports them across the circulation to different sections of the body, therefore playing a vital part in this mobility. Hemoglobin releases the oxygen as the blood enters the capillaries so that it may diffuse into the tissues. The flowchart shows this process as Oxygen Transport linked to Hemoglobin Binding, therefore stressing the vital link between hemoglobin and oxygen in enabling the transport mechanism. Little blood channels called capillaries link arteries to veins and enable the oxygen and nutrient flow between blood and bodily tissues. Delivered to the mitochondria in cells, oxygen is crucial in cellular respiration—a process that turns glucose and oxygen into energy. Emphasizing the role oxygen plays in energy generation, this stage is shown in the flowchart with O2 Delivery heading to Mitochondria. Apart from oxygen, another essential role of the circulatory system is nutrition transportation. Glucose and other nutrients are carried by the plasma, the liquid component of blood that moves vital elements all about the body. Plasma Transport shows the flow of nutrients throughout the circulation in the flowchart; glucose, shown as Glucose, is a vital nutrient transported to cells for energy generation. Glucose enters the cells via capillaries once it is in the circulation. From the blood into tissues, glucose travels in a process shown by the flowchart. Like oxygen, glucose reaches the Mitochondria where it is vital for generating energy via cellular respiration (Fig 1). As Energy Production shows, the maintenance of the energy levels needed for cellular functions depends on the flow of glucose and oxygen into the mitochondria.

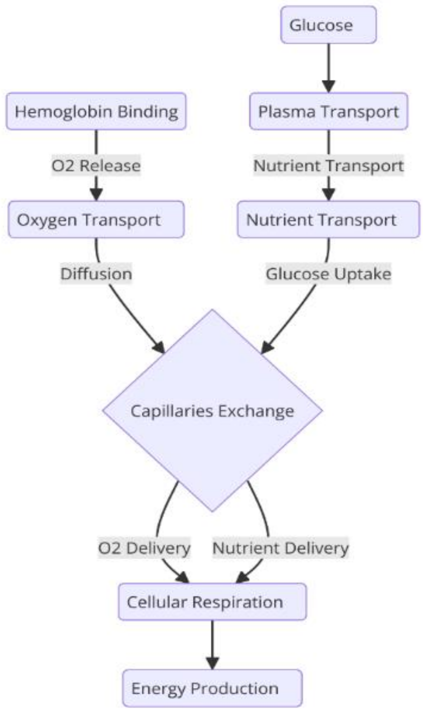

Fig. 1. The mathematical model of blood vessel operations in the oxygen and nutrition transportation

Between the blood and the tissues, oxygen and nutrient exchange occurs mostly in the capillaries. Under this mathematical approach, food supply and oxygen transport mostly occur from capillaries. The flowchart emphasizes this dual function by showing Oxygen Transport and Nutrient Transport meeting in the capillaries before moving into the cells. The capillary exchange guarantees that tissues get the glucose needed for energy generation and the oxygen necessary for metabolic activities. Once inside the cells, the oxygen and glucose are carried to the Mitochondria, the cell's powerhouse, where they are burned to create energy. Known as Cellular Respiration, this process mixes glucose and oxygen to generate ATP (adenosine triphosphate), which cells utilize for basic operations. The flowchart shows this by tying capillary exchange straight to mitochondrial energy generation and activity. Maintaining cellular energy and function depends on the complex mechanism by which oxygen and nutrients are transported via blood vessels (Fig .2). Under this mathematical model, hemoglobin carries oxygen to the tissues where it is released and used in cellular respiration. Analogously, glucose is carried by plasma and absorbed by cells where it also generates energy. Key to this process is the capillaries' ability to enable the exchange of oxygen and nutrients, therefore guaranteeing that tissues have the elements required for life. This bio-mathematical model emphasizes how well effective blood flow and nutrition delivery save the energy needed for cellular operation (Fig. 3.). Understanding how the body maintains its important activities depends on the interplay among oxygen transport, nutrition absorption, and energy generation; so, this mathematical model is a useful instrument for more thorough investigation of these interactions.

METHODS

We will now discuss the modeling of the oxygen and nutrient flow in blood arteries using diffusion equations for the concentrations of these components and reaction equations for their interaction with blood cells. Such equations and boundary conditions are shown here:

Diffusion equation for oxygen concentration *O (x,t)*is given *;*

D_0 - oxygen diffusion coefficient

k_0- oxygen reaction constant

$C_{blood}(x,y)$- blood cell concentration.

$$\frac{\partial^2 O(x,t)}{\partial t} = D_0 \frac{\partial^2 O(x,t)}{\partial x^2} - k_0 \cdot O(x,t) \cdot C_{blood}(x,t) \quad (1.1)$$

2. Diffusion equation for nutrient concentration N(x,t);

D_N— diffusion coefficient of nutrients

k_N— reaction constant of nutrients

$$\frac{\partial N(x,t)}{\partial t} = D_N \frac{\partial^2 N(x,t)}{\partial x^2} - k_N \cdot N(x,t) \cdot C_{blood}(x,t) \quad (1.2)$$

3. The reaction equation between blood cells, oxygen and nutrients

$$\frac{\partial C_{blood}(x,t)}{\partial t} = -\alpha \cdot O(x,t) \cdot C_{blood}(x,t) - \beta \cdot N(x,t) \cdot C_{blood}(x,t) \quad (1.3)$$

α-is the oxygen reaction constant.

β-is the nutrient reaction constant.

Boundary conditions

For modeling, boundary conditions must be specified. As an example, the following boundary conditions can be used:

For oxygen concentration *O(x,t):*

Left boundary (x = 0): Concentration is constant. $O(0,t)=O_{left}$;

Right boundary (x = L): Concentration is constant. $O(L,t)=O_{right}$.

For nutrient concentration N(x,t):

Left boundary (x = 0): Concentration is constant. $N(0,t)=N_{left}$

Right boundary (x = L): Concentration is constant. $N(L,t)=N_{right}$

For blood cell concentration $C_{blood}(x,t)$:

Left boundary (x = 0): Concentration is constant. $C_{blood}(0,t)= C_{blood\ left}$

Right boundary (x = L): Concentration is constant. $C_{blood}(L,t)= C_{blood\ right}$

To solve diffusion equations using the finite difference method (FDM), we transform partial differential equations into difference equations. Let's look at each of the equations and solve them for the one-dimensional case using FDM.

1.Diffusion equation for oxygen concentration $O(x,t)$ is given;

$$\frac{\partial^2 O(x,t)}{\partial t} = D_0 \frac{\partial^2 O(x,t)}{\partial x^2} - k_0 \cdot O(x,t) \cdot C_{blood}(x,t);$$

Then solving with FDM one demonical and deciding relatively

$$\frac{O_i^{n+1} - O_i^n}{\Delta t} = D_O \frac{O_{i-1}^n - 2O_i^n + O_{i+1}}{\Delta x^2} - k_O \cdot O_i^n \cdot C_i^n \quad (1.4)$$

$$A_i O_{i-1}^{n+1} + B_i O_{i-1}^{n+1} + C_i O_{i+1}^{n+1} = D_i$$

$$O_i^{n+1} = O_i^n + \Delta t[D_O \frac{O_{i-1}^n - 2O_i^n + O_{i+1}}{\Delta x^2} - k_O \cdot O_i^n \cdot C_i^n] \quad (1.5)$$

Finding coefficients

$$A_i = \frac{D_O \Delta t}{\Delta x^2};$$

$$B_i = 1 - 2\frac{D_O \Delta t}{\Delta x^2} - k_O \cdot t \cdot C_i^n;$$

$$C_i = \frac{D_O \Delta t}{\Delta x^2};$$

$$D_i = O_i^n. \quad (1.6)$$

2. Diffusion equation for nutrient concentration $N(x,t)$ and then solving with FDM one demonical then deciding relatively after solving finding coefficients

$$\frac{\partial N(x,t)}{\partial t} = D_N \frac{\partial^2 N(x,t)}{\partial x^2} - k_N \cdot N(x,t) \cdot C_{blood}(x,t)$$

$$\frac{N_i^{n+1} - N_i^N}{\Delta t} = D_N \frac{N_{i-1}^n - 2N_i^n + N_{i-1}^n - 2N_i^n}{\Delta x^2} - k_N$$

$$N_i^{n+1} = N_i^n + \Delta t[D_N \frac{N_{i-1}^n - 2N_i^n + N_{i-1}^n - 2N_i^n}{\Delta x^2} - k_N N_i^N C_i^n]$$

$$A_i = \frac{D_N \Delta t}{\Delta x^2};$$

$$B_i = 1 - 2\frac{D_N \Delta t}{\Delta x^2} - k_N \Delta t C_i^n;$$

$$C_i = \frac{D_N \Delta t}{\Delta x^2};$$

$$D_i = N_i^n. \quad (1.7)$$

3. The reaction equation between blood cells, oxygen and nutrients

$$\frac{\partial C_{blood}(x,t)}{\partial t} = -\alpha \cdot O(x,t) \cdot C_{blood}(x,t) - \beta \cdot N(x,t) \cdot C_{blood}(x,t)$$

then solving with FDM one demonical and deciding relatively after solving finding coefficients

$$\begin{aligned}
&\frac{C_i^{n+1}}{\Delta t} = -\alpha \cdot O_i^n \cdot C_i^n - \beta \cdot N_i^n \cdot C_i^n \\
&C_i^{n+1} = C_i^n + \Delta t[-\alpha \cdot O_i^n \cdot C_i^n - \beta \cdot N_i^n \cdot C_i^n] \\
&A_i = 0; \\
&B_i = 1 - \Delta t(\alpha \cdot O_i^n \cdot - \beta \cdot N_i^n); \\
&C_i = 0; \\
&D_i = C_i^n.
\end{aligned} \qquad (1.8)$$

CONCLUSION

It is also possible by using Python and differential equations to model the transport of oxygen and nutrients in blood vessels and then visualize the results. Below is an example of how to approach it using Python implemented in Google Colab. Mathematics has been used more in recent years for the explanation of the compacted circuit of oxygen and nutrient distributions in blood vessels (Fig.2). The simulation of blood circulation and oxygen as well as nutrients distribution allows anticipating the effects of parameters change such as narrowed arteries or reduced blood circulation on tissue condition [10,11,13]. Calculated models give information that may be used to develop better therapies by making one to realize how levels of oxygen and nutrients shift in time and space within the body.

The research introduced a mathematical model that examines the dynamics of oxygen and nutrient transport in blood arteries, which includes variations in oxygen concentration O(x,t), nutrient concentration N(x,t), and blood flow concentration C (x,t). The model combines blood pressure, flow velocity, and artery wall diffusion into tissues. Hemodynamics and tissue perfusion, crucial to cardiovascular physiology are better explained. This research's revolutionary methodology will improve computational cardiovascular disease detection and treatment. This investigation addresses a key need in modern medicine by enhancing diagnostic instrument prediction accuracy and refining treatment techniques for more effective and tailored treatments. Efficiency and relevance of the model promise to advance cardiovascular research and applications for therapy. The disorder known as atherosclerosis is one in which plaque accumulates within arteries, therefore constricting their path of flow.

Effects on Nutrient/Oxygen Transport: Reduced blood flow lowers the delivery of oxygen O $(x,t)$and nutrients N (x,t) to tissues, hence producing ischemia (reduced oxygen supply).Coronary artery disease, peripheral artery disease, stroke are the related diseases. The condition known as ischemic heart disease, often known as coronary artery disease, results from constricted coronary arteries lowering blood flow to the heart muscle. Affect on Oxygen/Nutrient Transport: Heart attacks or chest discomfort (angina) might follow from inadequate oxygen supply to the heart muscle. Chest discomfort, dyspnea, heart failure are the symptoms. Usually the legs, peripheral artery disease (PAD) is a cardiovascular disorder wherein limited blood supply to limbs results from constricted arteries. Effect on Oxygen/Nutrient Transport: Results in inadequate oxygenation of extremity muscles and tissues, therefore aggravating pain during physical exercise and compromising recovery. In extreme cases: tissue death, ulceration, and leg discomfort. The metabolic condition known as diabetes mellitus causes excessive blood sugar levels that over time damage blood vessels. Microvascular problems include diabetic retinopathy and neuropathy lower blood flow and hence affect the oxygen and nutrition supply to tissues. Kidney problems (diabetic neptropathy), eye impairment (diabetic retinopathy), inadequate healing of wounds. A collection of lung illnesses (including emphysema and chronic bronchitis) that obstruct airflow and complicate breathing. Effect on Oxygen/Nutrient Transport: The body's capacity to provide oxygen to tissues suffers when lung function is compromised, therefore lowering the blood oxygen levels. Symptoms include tiredness, dyspnea, less exercise ability. The chronic illness known as heart failure describes a situation when the heart cannot effectively pump blood, therefore causing inadequate oxygen and nutrition delivery. The development of both Python and the movement of oxygen and nutrients through blood vessels depends on each other. One of the most essential programming languages for current technology because of Python's adaptability, simplicity of use, and large libraries; it helps to enable developments in data science, artificial intelligence, and automaton. By using Python to model the transport of oxygen and nutrients in blood vessels, you can simulate the dynamics of transport using differential equations and visualize the results. Here is an example of how to approach it using Python in Google Colab.

DISCUSSION AND RESULTS

Accordingly, this work has envisioned the study of oxygen and nutrient transport in blood vessels and mathematical and computational techniques for their representation particularly with regard to disease development and blood circulation irregularities. Human's circulation is the missing link without which tissues cannot function healthily or even function at all as modeled by the movement of oxygen and nutrients through blood arteries. Nevertheless, interruptions of such extent in the transportation of blood through vessels are capable of resulting in several cardiovascular diseases which may include atherosclerosis, coronary artery diseases, and peripheral artery diseases. A discovery that we make out of this analysis is that it is helpful to model transport of oxygen and nutrients to determine how alterations in physiology or pathophysiology affect tissue equilibrium. Performing its role in patients with cardiovascular diseases, the arteries constrict and the blood flow decreases which in turn restricts the delivery of oxygen and nutrient to the tissues. Thus, using computer simulations of mathematical models, researchers and clinicians are able to demonstrate shifts in the dispersion of these elements and potential interferences. But it remains as a matter of controversy as to the role that Python undertakes in these models.

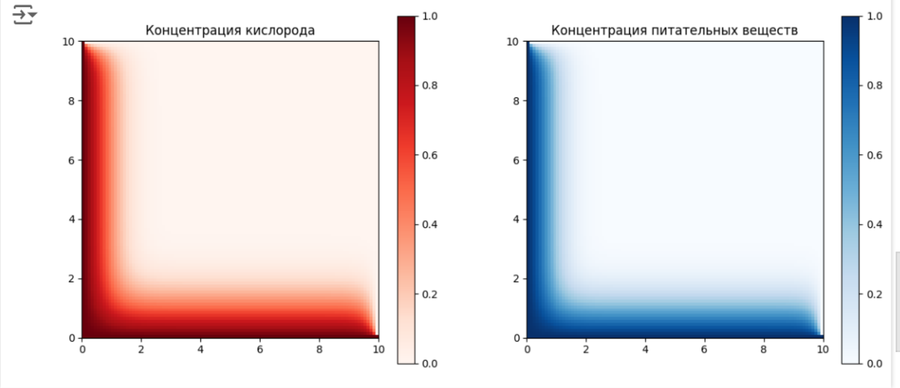

Fig. 2. Results of mathematical modeling the transport of oxygen and nutrients in blood vessels

Today, as Python has become one of the widely used and universal languages, it is engaged in computational modeling more and more often, and even in the medical field. Python has numerous libraries for numerical computation among them being SciPy library which assists in performing numerical computation for simulating blood flow and diffusion process in arteries together with MatPlotlib library that assists in visualization (Fig 2). Such simulation using Python enables the research to address such real-life problems as the arterial blockage, oxygen diffusion problem, probable stenting or bypass surgery. As can been see from the Table 1 tissues need oxygen for cellular respiration, hence blood vessel diffusion is essential. The diffusion-advection equation describes arterial oxygen concentration. This equation simulates oxygen molecule diffusion and advection. Most nutrients are transported by diffusion and advection, but glucose interacts with circulation proteins and cells. No direct response equation exists between blood cells and nutrients like the hemoglobin-oxygen interaction. Insulin, which helps cells absorb glucose, regulates nutrition intake and metabolism. The nutrition transfer equation emphasizes diffusion to maintain a bloodstream-to-tissue concentration gradient.

Table 1. Type of about equation

Type of Equations	A_i	B_i	C_i	D_i
Diffusion for oxygen concentration	$\frac{D_O \Delta t}{\Delta x^2}$	$1-2\frac{D_O \Delta t}{\Delta x^2}-k_O \cdot t \cdot C_i^n$	$\frac{D_O \Delta t}{\Delta x^2}$	O_i^n
Diffusion equation for nutrient concentration	$\frac{D_N \Delta t}{\Delta x^2}$	$1-2\frac{D_N \Delta t}{\Delta x^2}-k_N \Delta t C_i^n$	$\frac{D_N \Delta t}{\Delta x^2}$	N_i^n
The reaction equation between blood cells	0	$1-\Delta t(\alpha \cdot O_i^n \cdot -\beta \cdot N_i^n)$	0	C_i^n

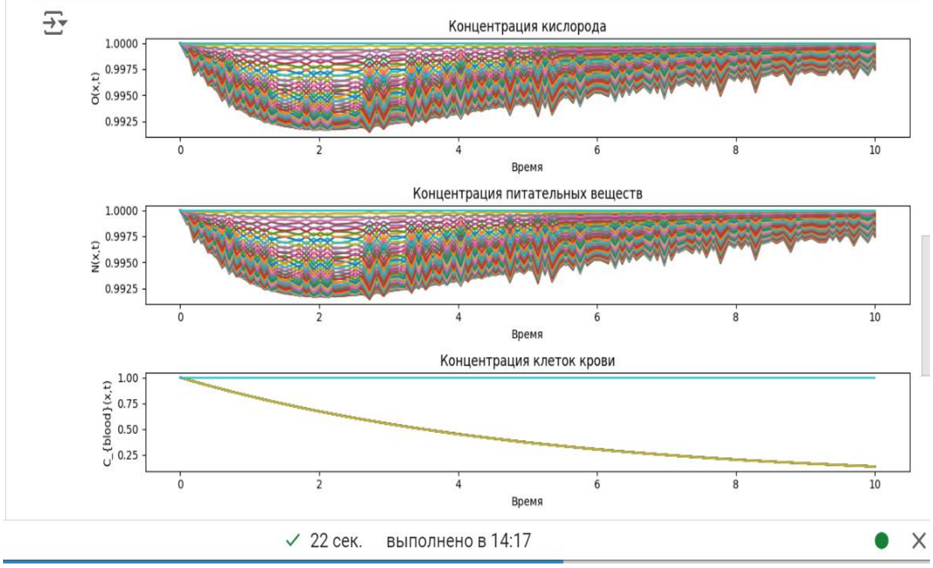

Fig. 2. Results of the concentration transport of oxygen and nutrients in blood vessels

The first plot is the graphical representation of a straight line y = 2c where c is the concentration of oxygen (C_{ox}(x,t)) over time. The graph reveals small fluctuations in the oxygen levels within the range of 0 to 10 units with a relatively steady progress of the value near to 1.000. This stability could indicate high ordered or homeostasis system of which oxygen concentration is relatively variable with some deviation from the mean, which would mean about periodic oxygen delivery or oxygen release in a biological sense and a simulation model. Interpretation: Such changes might be as a result of physiological factors such as uptake and exchange of oxygen in which amounts are understood to vary with time. Such a slowing down may be associated with the considerations that after a certain period of fluctuation the cycle is shifting to a quasi-steady-state where the oxygen consumption and re-synthesis rates equalize.

The second plot is a concentration of nutrients *(C_{nutr} (x,t))* over time. Similar to what was registered with the case of oxygen concentration, the fluctuation in the nutrient cycles in the ecosystem does not influence the relative values of the parameter, which stays near to 1.000 on average[8,9,11]. These higher or otherwise normal alternations could be suggestive of a rhythm in the need for nutrients and availability of the nutrients. It also indicates growth in this area as a result of a stable nutrient supply as is seen in engineered systems or biological models of tissue in which nutrient delivery is moderated by usage. Interpretation: It implies that the nutrient concentrations are kept fluctuating and will probably be controlled in a system where nutrient demand for instance from cells is replenished by Nutrient delivery for instance through diffusion or perfusion. The variations may therefore be because of the changes in cells or tissues depending on the metabolic requires at that time. The third plot show the count of blood cells indicated by the word platelet (C_{blood} $(x,)$ That is why the function $P(x,t) = p(x,t)/\mu$ has been depicted decreasing with time as represented below. This could mean that there are no more blood cells in circulation at any one time and any blood cells that existed in the system are destroyed or undergo a process of rapid degeneration (apoptosis), without replacement. This degradation is first order which further indicates that the blood cells are use up by this rate or are participating in this rate. Interpretation: It was found that the changes in blood cell concentration happened gradually which might indicate that blood cells are employed, for example if the cell is placed in a culture medium or incorporated into a tissue construct. This form may seem to indicate if this is a biological system therefore, there must be a condition that is pathological in that there is a destruction rate that is much higher than the rate of production of these blood cells [8,9,10].

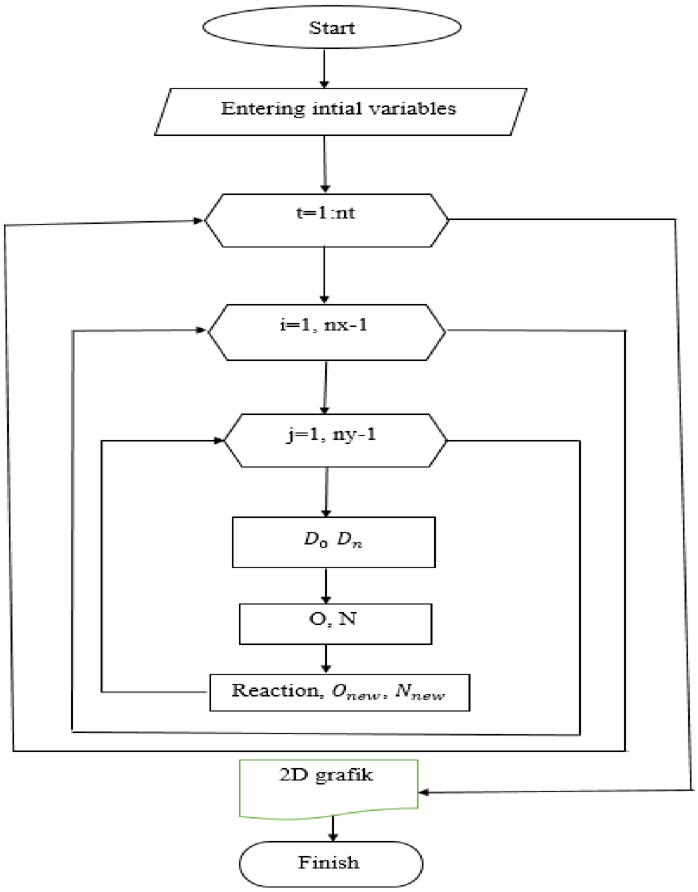

Fig. 3. Block –schema of Mathematical modeling the transport of oxygen and nutrients in blood vessels

Oxygen and Nutrient Concentrations: Meanwhile, concentrating on oxygen and nutrients, these parameters are considered as medium and fluctuating slightly around a constant [10,11,13]. This indicates that the system is indeed capable of keeping these parameters de facto constant during the course of the experiment time magnitude of minor variations may indicate metabolic or supply-demand related changes. This kind of behaviour is typical of engineered systems developed to endorse biological activities, or in vivo conditions which are well monitored. Blood Cell Concentration: On the other hand, the blood cell concentration profile is more or less gradual decrease with time and they do not seem to regenerate which may indicate that the substance is gradually being used up. This indicates that either these blood cells were not being produced in this animal to begin with, or there was a cycle, which constantly removed these blood cells- for example, by being destroyed, degenerating or being metabolized. It affords an indication of how the system manages the amount of oxygen and nutrient when specific intervals are observed [10,11,13]. However, the continuous decline in the blood cell concentration increases the question of whether the system can maintain a functional level of blood cells. The future work could be aimed at improving the blood cell production or identifying the process that leads the depletion of the cells so as to avoid the complete loss as seen with the current model.

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