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Editorial office
Uniwersytet Zielonogórski,
Wydział Mechaniczny,
Zakład Inżynierii Biomedycznej,
ul. Licealna 9, 65-417 Zielona Góra

Technical editor
Tomasz Klekiel

Cover design
Justyna Gołąb

Human red blood cell properties and sedimentation rate: a biomechanical study

N. KIZILOVA[1], L. BATYUK[2], V. BARANETS[3]

Key words: *blood rheology, erythrocyte sedimentation rate, allergy, medical diagnostics*

1. Introduction

Human blood is widely used for clinical diagnostics due to its easy accessibility and high sensitivity for any metabolic disorders and diseases. Blood is a unique tissue circulating between cells, tissues and organs of the body and carrying the products of the tissue metabolism, new growth, necrosis, and other physiological processes [1]. In that way, blood is the most proper tissue for easy and detailed diagnosis of the body metabolism and state of its organs and tissues. Here a brief review on electric and mechanical properties of red blood cells (RBC) that can be useful for clinical diagnostics is presented. Those properties are responsible for differences in the RBC aggregation and sedimentation (erythrocyte sedimentation rate test, ESR) in healthy humans and patients with different acute and chronic diseases. The physical forces between RBC suspended in the blood plasma (BP), discrete and continual models of blood are presented.

2. Materials and methods

Native venous blood samples were collected from 20 patients (10 males and 10 females; average age 59 ± 9 years) and split into small portions 1 ml. One portion was studied as a control test while into other portions small amounts of the drugs prescribed to the patient or potential allergens were added. All the portions have been placed in the standard glass tubes (d=1mm, L=100mm) and microtubes (d=0.5 mm, L=50mm). The tubes were placed in a rack in a vertical position for 3 hours at the room temperature. The height h of the transparent layer of blood plasma in the upper part of each tube has been measured each 10 min. As a result of the study the sedimentation curves $h(t)$ have been obtained for each tube. The curves have been smoothed by Bayesian filter and the time derivative curves $h'(t)$ have been computed and analyzed together with $h(t)$ curves.

3. Results and discussions

The curves $h'(t)$ exhibit similar dynamics with the noticeable maximum at $t = t_{max}$, which corresponds to the maximal velocity of sedimentation followed then by some decrease in the ESR caused by the influence of the settled aggregates accumulated at the bottom of the sedimentation tube [2]. The time t_{max} was shown to be a good diagnostic index, which almost independent of the initial concentration of RBC and BP viscosity, and reflects the RBC aggregation rate only [1,2]. The difference between the control sample and the sample affected by potential allergens were more distinct in the microtubes with smaller amount of the blood needed. Due to instability of settling, different curves h(t) have been registered for different portions of blood of the same person.

[1] N. Kizilova, Warsaw University of Technology, Nowowiejskast., 24, 00-665 Warsaw, Poland,
e-mail: n.kizilova@gmail.com
[2] L. Batyuk, Kharkov National Medical University, Nauki av., 2, 61022 Kharkov, Ukraine,
e-mail: liliyabatyuk24@gmail.com
[3] V. Baranets, V.N. Karazin Kharkov National University, Svobody sq., 4, 61022 Kharkiv, Ukraine,
e-mail: cherevko.vita@gmail.com

The mixture model of blood as a three-phase continuous media composed of the free BP (phase 1), RBC aggregates (phase 2) and BP captured inside the aggregates (phase 3) based on the mass and momentum balance equations, and aggregate kinetics equations is used for the 1d modeling of RBC sedimentation [2]. The hyperbolic system of equations for the mass and volumetric concentrations of RBC, and average volume of the RBC aggregates has been obtained and solved by the method of characteristics. The system has three families of characteristics producing four regions by their cross sections (Fig. 1b). Depending whether the third characteristics is positive or negative, two different scenarios can be found. The first zone corresponds to the clear BP region; zone 2 is filled by single RBC and small aggregates freely distributed in BP. Zone 3 corresponds to the aggregating RBCs and settling aggregates, while zone 4 is the compact zone composed by the resting aggregates with a small amount of captured BP. Depending on the model parameters the height h_2 of the zone 2 may be short ($h_2 << h_3$ Fig.1a) or long ($h_2 >> h_3$ Fig.1b) at the same values h_1, h_4. In the experiments both cases have been observed. The zone 2 has been present as semi-transparent pink or red colored region. Most likely, the zone 2 corresponds to the BP released at high vertical velocities from the aggregates due to instability and rapid compression of the RBC network in the zone 3 [2]. Based on the model, the expression for the time t_{max} has been obtained.

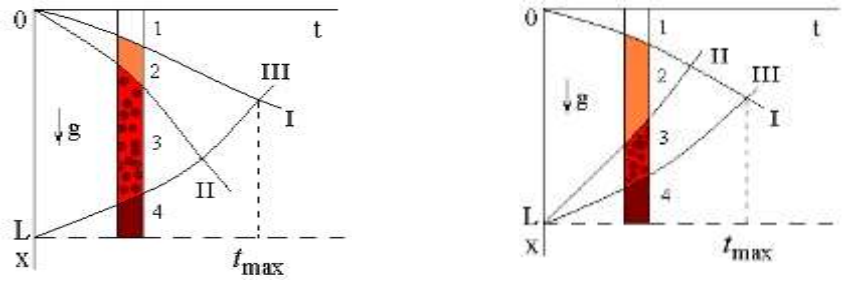

Fig. 1. Schematic representation of the sedimentation dynamics according to three characteristics (I, II, III) with positive (a) and negative (b) 2-nd characteristic

4. Conclusions

The ESR is a simple and convenient diagnostic test, but the ESR curves h(t) carry more valuable information on aggregation dynamics and specific interactions between RBC, BP proteins, products of the tissue decay, apoptosis or new growth. The differential $h'(t)$ curves show stable time intervals of t_{max} in different samples of the same person. The modified ESR test when a small portion of potential allergen (pollen, drug or food allergens) is added to the blood is very helpful in revealing different food and drug allergy. It gives a new tool for fast, cheap and reliable quantitative estimation of the allergy and personal compatibility with prescribed medicine. An addition of the allergen can lead either to acceleration or to deceleration of the ESR in comparison with the control probe. Due to instability of the sedimentation process when occasional formation of a large aggregate at the top of the sedimentation tube could fall down faster and accelerate the process, the study of several (3–5) probes with the same allergen could be recommended. The decision can be made on the averaged value of t_{max} and averaged ESR curves. The developed model confirm t_{max} strongly depend on RBC aggregation rate and slightly depend on the patient specific RBC concentration in the sample.

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