HYDRODYNAMIC PROPERTIES OF ERYTHROCYTES

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In the mechanism of two widely prevalent methods of laboratory investigation, the RGA and the ROE, /RGA = hemagglutination reaction, ROE = erythrocyte sedimentation rate/ a significant role is played by the properties of combination of erythrocytes. It seems to us that the first step in their investigation is determining the hydrodynamic properties of a single erythrocyte.

With this aim we prepared a suspension of erythrocytes in a dilution of $1:10^5$ in an 0.85% solution of NaCl, placed them in a glass beaker and examined them with a microscope objective magnification of 80 times.

Observations showed that for the predominant part of the time the erythrocytes settle with a position of the surfaces of the disk perpendicular to the axis of precipitation and only immediately at the wall of the vessel -- "with the edge downward." According to Chizhevskiy /1/, on the other hand, the erythrocytes are mainly oriented "with the edge downward." The contradiction is explained by the difference in conditions under which the observations were made. We repeated the observations of Chizhevskiy in a narrow chamber with the microscope at a horizontal position and established that the share of erthrocytes which were precipitating "with the edge downward" was significant, since the greatest number of them were positioned near the wall, however the centrally located ones settled with the flat surfaces perpendicular to the direction of settling.

The point is that Chizhevskiy observed erythrocytes with a microscope magnification of 600 times and as a result of an insignificant degree of sharpness only those located in the vicinity of the wall fell into the field of vision. The use of weaker magnifications, and also observation in wider vessels with the microscope in a vertical position, lead to the conclusion that the general regularity is the settling of erythrocytes with the flat surfaces perpendicular to the direction of settling, and the disposition "with the edge downward" is an exceptional case, explained by the conditions at the wall.

The nature of settling of erythrocytes in a standing liquid is found in conformity with the solution of Ye. N. Zhukovskiy's problem for a flat disk.

The theory comes to the conclusion that with a change of the position of the disk, forces emerge which return it to the original position, perpendicular to the flow of the liquid. In a narrow chamber a convection current of the fluid emerges which causes a drop of the pressures on the disk shaped erythrocyte. As a result of friction against the wall, the closer the layers of liquid are disposed to it then the greater the pressure. In the zone where the pressure drops, forces act on the erythrocytes which orient their flat surfaces parallel to the wall of the vessel. According to Poiseuille's law, the difference of pressures decreases rapidly with the withdrawal of the layer from the wall and has practical importance only in a certain zone in the vicinity of the wall.

We also investigated the rate of settling of individual erythrocytes. With this aim the microscrew of the microscope was set on zero, and by rotating the macroscrew we focused one of them which was found on the surface of the solution. In following the movement of this erythrocyte it is maintained in the field of vision by rotating the microscrew, and every two minutes a note is made of the number of divisions it was necessary to turn the screw for this purpose. Since the value of a division equals 0.002 mm, then the rate of settling of the erythrocyte equals $x \cdot 0.002/2 = 0.001\ X$ mm/min. Statistical processing of 200 calculations showed that the average speed of settling of an erythrocyte was 20--50 microns/min.

The Reynold's number $R = lv/\nu$. The kinematic viscosity of an 0.85% solution of NaCl has the order of 10^{-2} cm^2/sec; the linear dimension of an erythrocyte is 10^{-4}, and the speed of its settling 10^{-4} cm/sec. For an erythrocyte which is placed in an 0.85% solution of NaCl the Reynold's number has an order of 10^{-6}. Thus, according to the theory, in a frontal resistance, which is being experienced by the moving erythrocytes, there is a predominance of forces which cause friction and it is practically possible to disregard forces of an inertial origin. The viscosity coefficient of the medium has a greater effect than its density on the settling of erythrocytes.

By applying the method of dimensions we find that the frontal resistance, experienced by the erythrocyte,

$$Q = k\pi\eta r v. \tag{1}$$

With the established dimension of movement of the particle, the resistance encountered by it equals the apparent weight in the medium:

$$Q = P. \tag{2}$$

The erythrocyte, having a biscuit shaped form, may in the first approximation be viewed as a disk with the same radius and height. Its weight in the medium

$$P = \pi r^2 hg/d_1 - d_2/. \tag{3}$$

On the basis of (1)--(3) we have

$$k\pi r v\eta = \pi r^2 hg[d_1 - d_0] \tag{4}$$

and

$$k = (rhg[d_1 - d_0])/\eta v \tag{5}$$

(for an erythrocyte of average dimensions $r = 3.75 \cdot 10^{-4}$; $h = 1.8 \cdot 10^{-4}$ and $v = 0.8 \cdot 10^{-4}$ cm/sec). The viscosity of a η 0.85% solution of NaCl with sufficient approximation may be taken as equal to the viscosity of water -- 0.0106 poise.

The density of blood d = 1.055; plasma d' = 1.026. According to the new data of Chizhevskiy /2/, the erythrocyte occupies 32% of the volume of blood; consequently,

$$d = \frac{32 d_1 + 68 d'}{100}$$

and

$$d_1 = \frac{100 d - 68 d'}{32} = 1.117. \tag{6}$$

The density of the solution of NaCl, found experimentally (6), is d_2 = 1.005. Substituting these values in (5), we obtain k = 8.67. Thus the frontal resistance of the erythrocyte

$$Q = 8.67\pi r\eta v. \tag{7}$$

This exceeds the frontal resistance of a globule, determined by the formula of Stokes $Q = 6\pi r\eta v$, also established empirically. Therefore, for determining the rate of settling of an erythrocyte it is incorrect to use the known formula v = (2/9) $(d_1 - d_2)/\eta) gr^2$. Satisfactory values are obtained when using the formula resulting from (5):

$$v = \frac{rhg[d_1 - d_2]}{8.67\eta}. \tag{8}$$

The slowed down settling of the erythrocyte, in comparison with a globule, is explained by the principles of hydrodynamics. At the edges of a moving erythrocyte a great breaking potential is created, and behind it a greater eddying of the fluid emerges, which causes a more significant frontal resistance.

The equation (8) may be used in an analysis of the settling of agglomerates of erythrocytes, which play a significant role in the effects of the RGA and the ROE.

Conclusions

1. During the settling of an erythrocyte in a motionless fluid, it is oriented with the flat surfaces perpendicular to the axis of falling, which corresponds to the laws of hydrodynamics.

2. The settling of an erythrocyte "with the edge downward" in a narrow capillary and in the vicinity of the wall of a wide vessel is an exceptional case and is explained by the law of Poiseuille concerning the drop in pressure of a fluid at the wall of a vessel.

3. As a result of the greater frontal resistance of an erythrocyte as compared to a globule, the formula of Stokes is not applicable for the rate of settling of an erythrocyte. On the basis of experimental data, a formula has been derived which takes into consideration the hydrodynamic peculiarities of the erythrocyte.

Literature

1. Chizhevskiy, A. L., Structural Analysis of Moving Blood, Part 3, Chapter 2, 1959.

2. Chizhevskiy, A. L., Structural Analysis of Moving Blood, Part 1, Chapter 4, 1959.