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LASER DOPPLER SPECTROSCOPY METHOD IN RESEARCHES OF BLOOD HYDRODYNAMICS

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The studying of rheologic properties of blood is nowadays an actual task from medical point of view. It is known that most diseases, like, for example, coronary ischaemia, myocardial infarction, renal insufficiency, diabetes and others, as well as employment of artificial blood substitutors are followed by the changes of these properties (1). We have found a relation between pathology of blood vessel walls and hydrodynamic flow conditions (2, 3).

The purpose of this work was to analyse possibilities of researches of blood rheology with laser Doppler spectrometer (LDS). This method is based on measurement of magnitude of Doppler shift of frequency of laser irradiation dispersed by particles that are moving along with the liquid (in this case - by erythrocytes). The experimental diagram is shown on fig. 1 (4).

He-Ne laser irradiation (1), reflected by the mirror (2) fell on semitransparent mirror (3). On this mirror laser beam was divided into two beams of equal intensity. Both beams, being reflected from 100% mirrors (4), passed through telescopes (5), that magnified the diameter of pencil of beams and lens (6), focusing these beams into one point inside of the capillary tube (7).

The characteristic size of measuring volume created due to laser beams intersection behind lenses (6), was about 30 mkm.

The irradiation dispersed from the measuring volume was focused on photoelectronic multiplier prism (EMP) (9) with employment of objective lens-receiver (8). The signal from EMP came to spectrum analyser (10), from which information about the magnitude of Doppler shift was received.

The measurement accuracy was determined by finite dimensions of the measuring volume, which led to the broadening of Doppler spectrum. In our case we could ignore the flight-time broadening compared with that of the gradient in heparinized capillary tubes with the inner diameter less than 500 mkm.
The scanning with measuring volume along the capillary tube diameter was a technique used to measure the blood velocity profile $V(r)$ in the narrow glass capillary tube.

The following formula was used for the approximation of experimental points:

$$V(r) = \frac{V_o}{1 - \left(\frac{r}{R}\right)^x}$$

where $V_o$ - maximum liquid flow velocity in capillary tubes, $R$ - capillary tube radius.

The formula comes from the analysis of Navier-Stokes' equation and Shvedov-Bengame's model for the axial-symmetric flow. For Newton's liquids the exponent "x" is 2.

The velocity profiles of water flow with polystirole latex, rheopolyglucinum with polystirole latex and donor's blood diluted with physiological solution were measured in the capillary tubes of 400 to 700 mm diameter. The polystirole latex was always added to create dispersion with its particles and it didn't cause any influence upon the rheology of liquid.

The results of experiments are shown on the diagrams, where the absciss is r-coordinate (in rel. un.) and the ordinate is a measured velocity value.

During the first experiment water & polystirole latex flow profile was measured in the capillary tube of $\phi = 660$ mm. Fig. 2 shows the $V(r)$ dependence. The approximating curve exponent $x=1.8$ due to the asymmetric gradient broadening of Doppler spectrum. The diagram shows a good coincidence of experimental points with the approximating curve.

During the second experiment the velocity profile of non-Newton liquid - rheopolyglucinum - was measured. The diagram with $V(r)$ dependence is shown on fig. 3. It's evident that rheopolyglucinum flow velocity profile is considerably different to that of the water flow velocity. The approximating curve exponent $x=1.4$.

During further experiment we measured the velocity profile of donor's blood flow diluted with physiological solution up to $Ht=5\%$. Fig. 4 shows that blood differs considerably from the Newton liquid. We may also notice a good coincidence of experimental points with the approximating curve, which exponent $x=2.0$. 
We also carried out measurements of blood velocity profiles up to $Ht=15\%$, and it showed that the approximating curve exponent "x" increased with the increasing of haematocrit. The further increasing led to some serious difficulties provoked by multiple dispersion.

As a whole the work has shown that the LDS-method is a perspective one for the researches of rheologic properties of blood both being normal and pathologic.

References
Fig. 1.

Laser Doppler spectrometer of differential type.
Water flow velocity profile, capillary tube diameter $\phi = 660$ mkm.
Rheopolyglucinum flow velocity profile, capillary tube diameter $\phi = 440 \text{ mkm}$, approximating curve exponent $x=1.4$. 
Diluted blood flow velocity profile, capillary tube diameter $\phi = 660 \text{ mkm}$, approximating curve exponent $x=2.0$, haematocritis exponent $Ht=5\%$. 

![Graph showing dilution of blood flow velocity profile with capillary tube diameter and haematocrits exponent](image.png)