*Journal of Engineering Physics and Thermophysics, Vol. 73, No. 4, 2000*

# RHEOLOGICAL PROPERTIES OF THE WHOLE BLOOD OF RHEUMATOLOGICAL PATIENTS

**S. V. Vilanskaya[a], V. A. Mansurov[a], and N. P. Mit'kovskaya[b]**

UDC 612.13

*Using the method of nonstationary rheometry, the changes occurring in the rheological properties of the blood of rheumatological patients in plasmapheresis in the range of rates of shear of 1–10 sec$^{-1}$ at a temperature of 37°C were studied. These studies were paralleled by measurements of the hematocrit index to correct the viscosity of the blood. A statistically reliable mathematical dependence of the change in the rheological properties of blood in plasmapheresis has been constructed. The role of the rheological factor of blood as a possible additional diagnostic parameter in plasmapheresis has been evaluated.*

An effective method of medical treatment of rheumatological patients is therapeutic plasmapheresis [1]. It consists in removing a certain amount of the plasma of blood together with some pathological proteins from the organism. The amount of plasma removed is compensated for with dextrans, amino acids, and other solutions, and the losses of protein are compensated for predominantly with albumin and protein and, in small amounts, plasma frozen for 4–6 h after completion of the procedure. The therapeutic effect of the plasmapheresis is explained by the extraction of part of the pathophysically significant substances, such as immune complexes, antigenes, antibodies, and excess of a number of enzymes, bacteria, and their toxins.

A detailed analysis of the special literature on plasmapheresis revealed insufficient knowledge of the character of the effect of plasmapheresis on the rheological state of blood. It is known that its rheological properties are associated with the concentration of the proteins of plasma, and therefore removal of a portion of them may exert an important effect on such characteristics as hematocrit, aggregation and deformability of erythrocytes, plasticity, etc. [2]. The process of plasmapheresis alters the quantitative and qualitative composition of peripheral blood. Therefore, a change in the aggregate of the indicated characteristics in the process of plasmapheresis may exert a substantial effect on the rheology of blood.

The aim of the present work is:

a) to study the changes in the rheological properties of blood (viscosity) and the hematocrit index in each stage of the procedures in the course of plasmapheresis;

b) to construct a statistically reliable mathematical dependence of the change in the rheological properties of blood in plasmapheresis;

c) to evaluate the role of the rheological factor of blood as a possible additional diagnostic parameter in plasmapheresis.

It is known that the non-Newtonian behavior of blood at very low rates of shear is determined largely by the properties of the aggregates that are formed from erythrocytes. As the rate of shear increases, their size decreases to complete disaggregation, i.e., the blood viscosity decreases [3]. Flowing blood develops a certain balance between the processes of aggregation and disaggregation. Thus, we may assume that the rheological characteristics obtained by measurements in a wide range of rates of shear are associated mainly with the processes of aggregation of erythrocytes.

[a]Academic Scientific Complex "A. V. Luikov Heat and Mass Transfer Institute," National Academy of Sciences of Belarus, Minsk, Belarus; [b]Minsk State Medical Institute, Minsk, Belarus. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 73, No. 4, pp. 792-796, July–August, 2000. Original article submitted September 10, 1999.

 1062-0125/00/7304-0782$25.00 

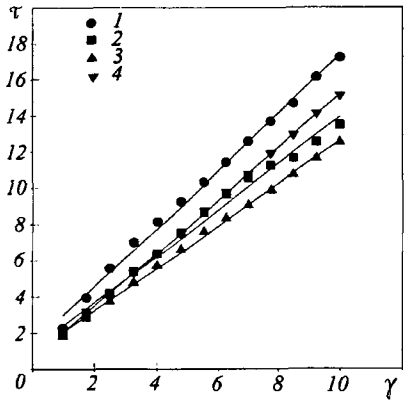


Fig. 1. Curves of flow of patient M.'s blood in plasmapheresis according to the procedure carried out (τ, shear stress, mPa; γ, rate of shear, $sec^{-1}$): 1) initial blood (H = 39.3%); 2) after hemodilution (H = 33%); 3) after taking 1 liter of blood (H = 28%); 4) after reinfusion (H = 36.3%).

Because of the complex pulsating character of blood flow in an organism, we may assume that a stationary regime of measurements in traditional rheological instruments does not account for the entire variety of mechanical behavior of blood. Therefore, a novel method and a viscosimeter were developed with a step motor used to drive coaxial-cylindrical measuring units [4].

Measurements were carried out with the working unit of the viscosimeter moving intermittently. A cycle of motion consisted of two phases: 1) a sharp rotation of the movable portion of the working unit through a small angle (1–2°) with a rate of shear of up to 500–1000 $sec^{-1}$; 2) a waiting period that can be regulated from several seconds to tens of milliseconds. The mean rate of shear in the working unit varies here from 0.1 to 100 $sec^{-1}$. The drive from the step motor makes it possible to realize a motion that would act destructively on the structure of a flowing suspension (blood). Since under conditions of pulsating flow the structure of the sample created by the erythrocytes of the blood is destroyed [5], the blood manifests Newtonian properties, and in this case we speak of the viscosity of the blood without allowance for structural factors [6].

The tests were carried out on blood samples of rheumatological patients. The blood specimens in each stage of the procedure of plasmapheresis were samples of:

1) initial blood prior to any intervention;
2) blood after hemodilution (intravenous injection of 1.5 liters of solutions);
3) blood after intake of 1 liter of blood;
4) blood after reinfusion (restoration) of centrifuged erythrocyte mass.

Heparin was used as an anticoagulant. The hematocrit index was determined in standard disposable heparinized capillaries using a laboratory TsG2-12 centrifuge.

Measurements in the viscosimeter were carried out at a predetermined temperature equal to 37±0.2°C and controlled by a semiconductor probe. Depending on the working unit, the volume of the blood sample was equal to 1.5–3 ml. The samples were placed in the viscosimeter working unit preliminarily heated to the given temperature. After this the dependence of the shear stress on the rate of shear was measured ($\dot{\gamma}$ = 1–10 $sec^{-1}$, 13 measurements). The small duration of one run (8 min) allows one to disregard the process of erythrocyte sedimentation.

Results of the measurements are presented in Fig. 1, where typical curves of the flow of the blood of patient M. and the hematocrit index (H) are presented for different stages of the procedure of plasmapheresis: before (initial blood) and during the procedure (hemodilution, taking of 1 liter of blood, reinfusion). It is seen that the change in the flow curve of the blood of the patient is adequate for medical procedures; the viscosity (the slope of the curves) decreases on introduction of the liquid and increases and tends to the viscosity of the

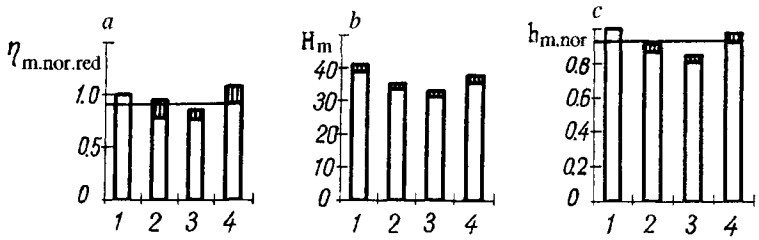


Fig. 2. Change in: a) the mean normalized blood viscosity reduced to a hematocrit index of 30%, b) the mean value of the hematocrit index (%), and c) the mean normalized value of the hematocrit index, depending on the procedure carried out in plasmapheresis [1-4) the same as in Fig. 1; the hatched rectangles denote the standard deviation; the horizontal line shows the deviation of the final value from the initial one].

initial blood after the reinfusion. The hematocrit index changes in the same manner. Such experiments were carried out for a sufficient number of patients (18).

The experimental data (flow curves) were processed by the least-squares method, using the Newtonian model, to obtain the value of the viscosity $\eta$. We note that the rheological characteristics for different series of experiments are similar, they differ only in numerical value. To carry out a uniform comparison of the results obtained, the data on $\eta$ were reduced mathematically to a single standard value of the hematocrit index (H = 30%) [7] and then were normalized to the viscosity of the initial blood (the first procedure). It turned out that the functional dependence of $\eta$ on H in the range of studied values of the hematocrit index (30–50%) obeys a linear law:

$$\eta = 0.1H - 0.64, \tag{1}$$

where $\eta$ is the viscosity, mPa·sec; H is the measured (instantaneous) hematocrit index, %; 0.1 and –0.64 are empirical constants for the investigated range of measurements of H.

From Eq. (1) we determine the viscosity increment as a function of the hematocrit-index increment:

$$\Delta\eta = 0.1\Delta H, \tag{2}$$

Using relation (2) and discerning that $\Delta H = 30 - H$ (note that we reduce to a smaller hematocrit index than the instantaneous one), we obtain a formula to calculate the reduced viscosity:

$$\eta_{red} = \eta + 0.1\,(30 - H), \tag{3}$$

where $\eta_{red}$ is the reduced viscosity of the blood that corresponds to a hematocrit index of 30%, mPa·sec.

Then we perform normalization of the measured viscosity in each procedure for each patient to the viscosity in the first procedure (the initial blood):

$$\eta_{nor.red} = \eta_{red}/\eta_1, \tag{4}$$

where $\eta_{nor.red}$ is the normalized reduced (H = 30%) viscosity of the blood of each patient to the blood viscosity in the first procedure; $\eta_1$ is the reduced viscosity of the blood of each patient in the first procedure (H = 30%), mPa·sec.

The data obtained from Eq. (4) for each patient were subjected to statistical processing to determine the mean normalized viscosity of the blood $\eta_{m.nor.red}$ reduced to a hematocrit index of 30% and its standard deviation for different procedures (see Fig. 2a). After hemodilution and taking of the blood, the value of $\eta_{m.nor.red}$ first decreases, attaining a minimum when the blood is taken, and by the fourth (last) procedure (reinfusion) it tends to the initial value (it amounts on average to 91% of the initial value).

This character of the behavior of $\eta_{m.nor.red}$ can be explained by a change in the concentration of proteins in the plasma; it is precisely due to this that a curative effect is attained. The literature contains information on the role of biochemical changes in the plasma in performing efferent therapy [8].

To determine the mean value of the hematocrit index $H_m$ and its standard deviation for different procedures, we carried out statistical processing of the data (see Fig. 2b). After the hemodilution and taking of the blood, the value of $H_m$ first decreases, attaining a minimum in taking of the blood, and by the fourth (last) procedure (reinfusion) it tends to the initial value (it amounts on average to 92% of the ititial value).

To carry out a uniform comparison of the patients with respect to the hematocrit index, we used its mean normalized value $h_{m.nor}$, having preliminarily determined the normalized value of the hematocrit index:

$$h_{nor} = H/H_1 , \tag{5}$$

where $h_{nor}$ is the value of the hematocrit index for each patient normalized to the hematocrit value in the first procedure; $H_1$ is the hematocrit index of each patient in the first procedure, %.

The data obtained from Eq. (5) for each patient were subjected to statistical processing to determine the mean normalized value of the hematocrit index $h_{m.nor}$ and its standard deviation in different procedures, after which the diagram shown in Fig. 2c was constructed, which shows the change in the mean normalized value of the hematocrit index in carrying out the procedures (after the procedures this value amounts to 92% of the initial value). The character of its change coincides with the character of the change in the mean normalized blood viscosity reduced to a hematocrit index of 30% for different procedures. To explain this, an attempt was made to construct a correlation between them. We obtained a correlation coefficient of 0.966, which is indicative of the presence of a linear dependence.

As a result we obtained the expression

$$\eta_{m.nor.red} = 1.33\, h_{m.nor} - 0.33 \tag{6}$$

(the confidence interval is ±0.26).

Expression (6) is a statistically reliable mathematical interrelationship of the change in the rheological properties of the blood in plasmapheresis and shows that a similar character of the change in these quantities exists, which allows one to use just one type of measurement to predict the rheological behavior of the blood. Thus, using Eq. (6), it is possible to evaluate the role of the rheological factor of blood as a possible additional diagnostic parameter in carrying out plasmapheresis.

In conclusion we note that for the first time the dynamic method of nonstationary rheometry was used to investigate the changes in the rheological properties of the blood of rheumatological patients in the course of plasmapheresis in the range of rates of shear of 1–10 $sec^{-1}$ at a temperature of 37°C. In all stages of the therapy we observed a change in the mean value of the viscosity, which first decreases (after hemodilution and taking of the blood), attaining a minimum in taking of the blood, and by the fourth (last) procedure (reinfusion) it tends to the initial value (it amounts on average to 91% of the initial value), which can be explained by a change in the concentration of proteins in the plasma.

The mean value of the hematocrit index reflects all stages of the performance of the therapy, and after the procedures it amounts on average to 92% of the initial value.

We have constructed a statistically reliable mathematical dependence of the change in the rheological properties of blood in plasmapheresis and have evaluated the role of the rheological factor of blood as a possible additional diagnostic parameter in plasmapheresis.

The authors express their thanks to Professor V. V. Kirkovskii, Doctor of Medical Sciences, for valuable advice and help in the organization of the investigations and to physicians D. D. Dus', F. N. Laban', and A. V. Starostin for help in preparing the samples of blood and to the Fund for Fundamental Research of the Republic of Belarus for financial support of this work, agreement B97-005.

## REFERENCES


1. S. D. Polozhentsev, A. N. Tulupov, K. Ya. Gurevich, and E. F. Krivozubov, *Klin. Med.*, No. 6, 77-80 (1991).
2. V. L. Levtov, S. A. Regirer, and N. Kh. Shadrina, *Rheology of Blood* [in Russian], Moscow (1982).
3. G. M. Savel'eva, G. D. Dzhivelegova, R. I. Shalina, and N. N. Firsov, *Hemorheology in Obstetrics* [in Russian], Moscow (1986).
4. V. A. Mansurov, V. V. Kulebyakin, and Z. P. Shul'man, *Vestsi Akad. Navuk Belarusi, Ser. Biyal. Navuk*, No. 3, 114-116 (1996).
5. V. A. Mansurov, Z. P. Shul'man, T. V. Yushkina, and I. A. Prolat, in: *Heat and Mass Transfer (Collection of Papers)* [in Russian], Minsk (1997), pp. 187-191.
6. V. A. Mansurov, Z. P. Shul'man, V. V. Kulebyakin, and I. A. Prolat, in: *Heat and Mass Transfer (Collection of Papers)* [in Russian], Minsk (1997), pp. 51-55.
7. G. M. Savel'eva, L. V. Antonova, and K. N. Prozorovskaya, *The Importance of Immunological Investigations in Obstetrics and Gynecology* [in Russian], Tashkent (1981).
8. E. G. Zotkin and A. M. Lila, in: *Abstracts of Papers Submitted to the 2nd Belarusian Conf. "Efferent Methods in Clinics,"* Minsk–Mogilev (1993), p. 36.