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COMPARATIVE ANALYSIS OF CHANGES IN THE RHEOLOGICAL PROPERTIES OF BLOOD AT STAGES OF TREATMENT OF CARDIOSURGERY PATIENTS

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It is shown that a heat operation under the conditions of artificial circulation exerts a marked influence on the rheological properties of blood and has a characteristic hemorheological picture during and after the operation. In this case, the value of the flow limit τ_0 is a hemorheological criterion reflecting the adequacy of the surgical correction of a cardiovascular pathology and the efficiency of the intensive therapy measures, which should be taken into account when such patients are treated.

In recent years, rather high interest has been shown in the problems of correction of hemorheological disturbances and in the methods of hemorheological therapy and prophylaxis [1]. The necessity of conducting clinical investigations of the rheological properties of blood stems from the fact that the latter have a part in the pathogenesis of various diseases and states and influence the pathological process and the clinical picture.

The result of an operation on the heart and/or vessels with the use of extracorporeal circulation depends on the adequacy of restoration of normal blood flow and the indices of hemodynamics, which in turn is closely related to the rheological properties of blood.

The aim of the present work is investigation and comparative analysis of changes in the rheological properties of blood in cardiosurgical patients at different stages of surgical treatment and in the early postoperative period.

Materials and Methods. We have examined 84 patients after the cardiosurgical operations under the conditions of artificial circulation: group 1, correction of acquired valvular diseases (25 patients); group 2, aorta-coronary/mammary-ocoronary shunting (44 patients); and group 3, reconstructive operations for the aorta (15 patients).

The hemorheological investigations were carried out at the beginning of the operation, at its end, and in the postoperative period: after 24 h and on the 2nd–3rd days after the operation.

The macrorheological investigations included measurements of the viscosity in the range of rates of shear 5–300 $\sec^{-1}$ on an AKR-2 rotary viscosimeter (Russia), estimation of the stability of a suspension, and calculation of the Casson viscosity (CV) and the flow limit τ_0.

The aggregation of erythrocytes was investigated on an ADE-5 automatic erythroaggregometer (Russia) by recording the intensity of the backscattering of light (λ = 630 nm) by a Couette blood flow of thickness 1 mm, which made it possible to estimate the following indices of this process: T_1, T_2, Ampl., β, and $I_a^{2.5}$.

The aggregation and deformability of erythrocytes were also estimated by indirect methods — calculation of the corresponding indices of aggregation and deformation (in relative units) [2].

The deformability of erythrocytes was investigated by the rigidometry method on an IDA-1 device (Russia) in the process of filtration of a suspension of erythrocytes in a buffer (Hct = 1%) through Nucleopor membrane filters (Russia) with pores 3 μm in diameter. The times of passage of the buffer t_b and the suspension t_{susp} through the filter were used for calculation of the rigidity index:

$$\mathrm{IR} = \frac{t_{susp} - t_b}{t_b} \frac{100}{\mathrm{Hct}_{susp}} .$$

The preoperative values of the rheological indices were considered as basic, and all the other values were considered as changes relative to them.

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TABLE 1. Changes in the Rheological Properties of Blood in Cardiosurgical Patients at the Stages of Surgical Treatment under the Conditions of Artificial Circulation ($\pm\Delta$, % of the control value)

Parameters	Stages of treatment	Group 1	Group 2	Group 3
T_1	I	$+115.2^{***}$	$+125.8^{***}$	$+56.1^{**}$
	II	–0.7	$+21.8^{**}$	–5.1
	III	–3.7	+1.4	-46.5^{**}
T_2	I	-15.6^{*}	–1.45	$+13.7^{*}$
	II	–6.7	–8.9	–8.7
	III	–5.3	+4.9	+2.3
Ampl.	I	$+45.6^{**}$	-16.9^{*}	-10.5^{*}
	II	$+43.9^{**}$	–4.2	$+25.3^{*}$
	III	$+14.9^{*}$	-17.5^{*}	-17.8^{*}
β	I	-13.5^{*}	-11.2^{*}	–7.8
	II	$+22.1^{*}$	+0.13	-18.9^{*}
	III	+0.3	–4.3	$+12.9^{*}$
$I_a^{2.5}$	I	-66.1^{**}	$+55.6^{**}$	$+20.0^{*}$
	II	$+22.0^{**}$	$+21.4^{**}$	-16.7^{*}
	III	-28.7^{**}	+8.3	$+20.0^{*}$
Hct	I	-23.8^{**}	-12.8^{*}	-11.8^{*}
	II	-33.4^{**}	-29.4^{**}	0
	III	-25.8^{**}	-24.1^{**}	$+13.3^{*}$
IR	I	–7.1	-18.2^{*}	–4.3
	II	-17.2^{*}	+0.6	+0.2
	III	+0.7	$+12.5^{*}$	-10.2^{*}
CV	I	$+86.2^{***}$	$+42.8^{**}$	+5.3
	II	$+45.9^{**}$	$+28.7^{**}$	+5.8
	III	–79	$+19.8^{*}$	$+70.9^{***}$
τ_0	I	$+30.0^{**}$	$+21.9^{**}$	$+77.8^{***}$
	II	$+35.9^{**}$	$+18.6^{*}$	$+42.0^{**}$
	III	-19.5^{*}	-44.9^{**}	–7.7

Note: I, beginning of the operation; II, end of the operation; III, after the operation; *, $p < 0.05$; **, $p < 0.01$; ***, $p < 0.001$.

The results of the investigation were processed by the nonparametric methods of statistical analysis with the use of the Dann, Kruskal, and χ^2 criteria. The differences were considered as reliable at $p < 0.05$.

Results and Discussion. At the beginning of artificial circulation, the level of hemodilution was practically equal in the patients of groups 2 and 3 and was the highest in the patients of group 1. The formation of this hemodilution led first of all to a decrease in the relative viscosity of blood ($p < 0.05$); however, at the same time, the Casson viscosity was increased in all the groups of patients ($p < 0.05$), which points to the fact that the role of the cellular

chain in the formation of the rheological properties of blood increases at this stage. As a result, the totality of the changes in all the rheological parameters led to an increase in τ_0, which was the smallest in group 2 ($p > 0.05$) and the largest in group 3 ($p < 0.05$). The beginning of artificial circulation was also characterized by a decrease in the aggregation of erythrocytes; the time T_1 increased first of all ($p < 0.05$). The dimension of the erythrocytic aggregates increased only in the patients of group 1. In this case, β and the deformability of erythrocytes remained unchanged in all the patients ($p > 0.05$).

At the end of the operation the aggregation of erythrocytes was enhanced in all the groups of patients. In this case, the time T_1 remained increased in the patients of group 2 and was decreased in groups 2 and 3 ($p < 0.05$) and the time T_2 was decreased in all three groups ($p < 0.05$). At the same time, the dimension of the cellular aggregates was decreased only in group 2 ($p < 0.05$); in the other groups, this index was significantly increased ($p < 0.05$). The disaggregation activity remained unchanged in the patients of group 2, was markedly decreased in the patients of group 1, and was increased in the patients of group 3. The artificial circulation had no influence on the deformability of erythrocytes in the patients of groups 2 and 3; however, the index of deformability of erythrocytes was significantly improved in group 1 ($p < 0.05$). It should be noted that to the end of the operation a marked hemodilution, as compared to the initial one, was observed in the patients of groups 1 and 2, while the hematocrit reached practically the preoperative values in group 3. These changes manifested themselves as a decrease in the relative viscosity of blood in groups 1 and 2 and as an increase in this index in group 3. We simultaneously registered the reliable increase in the Casson viscosity in groups 1 and 2 ($p < 0.05$) and the uncertain increase in this index in group 3 ($p > 0.05$) (see Table 1). The combination of the macro- and microrheological changes at this stage resulted in a further increase in τ_0 in all the groups of patients, which was the largest in group 3.

In the postoperative period the aggregation activity of erythrocytes remained unchanged in the patients of groups 1 and 2 and continued to increase in the patients of group 3, first of all due to the decrease in the time T_1 ($p < 0.05$). At the same time, the disaggregation of cells increased very moderately in the patients of group 2, remained practically unchanged in group 1, and decreased in group 3; in this case, the resistance of the cellular aggregates to the hydrodynamic breakdown increased ($p < 0.05$). The deformability of erythrocytes decreased in the patients of group 2, remained practically unchanged in group 1, and increased in group 3. The last observation can be considered as a factor compensating, first of all, the high level of hematocrit, which decreased by 20–25% in groups 1 and 2 and increased by 20–25% in group 3. As a result, the relative viscosity of blood decreased in groups 1 and 2 and significantly increased in group 3. The hemoconcentration appeared in group 3 with increase in the Casson viscosity. In all probability, the same increase in the Casson viscosity in group 2 was not due to the hemoconcentration but due to the increase in the viscosity of plasma against the background of the common metabolic changes in the ischemic patients.

Thus, the totality of the macro- and microrheological changes in each group resulted in a decrease in the value of τ_0, as compared to the initial value. The largest decrease in this index was observed in the patients of group 2, which is due to the restoration of normal systemic blood flow. In the patients of group 1, the decrease in τ_0 was more moderate and was dependent on the restoration of normal intracardiac hemodynamics. In the patients of group 3, it remained practically unchanged, which can be considered as a "negative" result that is due to the high hematocrit, which is disadvantageous from the rheological viewpoint because it creates an additional load on the myocarditis in the process of formation of blood flow.

The results obtained allow the conclusion that a heart operation under the conditions of artificial circulation influences the rheological properties of blood and each group of patients has its own characteristic hemorheological picture during and after the operation. In this case, the flow limit τ_0 is a criterion that, from the hemorheological viewpoint, reflects the adequacy of the surgical correction of a cardiovascular pathology and the efficiency of intensive therapy measures, which should be taken into account when such patients are treated.

CONCLUSIONS

1. The hemorheological changes arising in patients as a result of the surgical correction of acquired valvular diseases are due to the normalization of central hemodynamics and are characterized by a deterioration of the aggregation ability of erythrocytes, an improvement of their deformability, and a decrease in the viscosity of blood and in its flow limit.

2. In the patients subjected to aorta-coronary/mammary-coronary shunting, the hemorheological changes are less pronounced due to the normalization of local (coronary) blood flow and are characterized by a decrease in the aggregation ability of erythrocytes along with an increase in the stability of the cellular aggregates, an improvement of the deformability of erythrocytes, a significant decrease in the flow limit of blood, and an increase in its viscosity.

3. The hemorheological changes in patients subjected to reconstruction operations for the aorta are due to the large volume of the surgical intervention and are characterized by an increase in the hydrodynamic stability of the erythrocytic aggregates, a decrease in the deformability of erythrocytes, an increase in the viscosity of blood, and the absence of influence on the flow limit of blood.

NOTATION

CV, Casson viscosity, mPa·sec; τ_0, flow limit, N/m^2; T_1 and T_2, times of formation of linear and three-dimensional aggregates, sec; Ampl., characteristic of the final dimension of the aggregates (amplitude), rel. units; β, total hydrodynamic strength of the aggregates, sec^{-1}; $I_a^{2.5}$, index of strength of the largest aggregates, %; Hct, hematocrit, %; t_b and t_{susp}, times of passage of the buffer and the erythrocytic suspension through the filter, sec; IR, rigidity index, rel. units; λ, wavelength, nm. Subscripts: a, aggregate; b, buffer; susp, suspension.

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