RHEOLOGIC PROPERTIES OF BLOOD DURING LONG- AND SHORT-TERM ADAPTATION TO MUSCULAR ACTIVITY

V. N. Levin and A. V. Murav'ev

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Prolonged muscular training reduces the viscosity of the blood at rest [3, 9] and the reduction of viscosity of the blood is combined with moderate hemodilution [5, 6]. The opposite process, namely hemoconcentration, while it leads to an increase in the oxygen content per unit volume of blood, nevertheless loses much of this advantage because of the reduction in its flowability [11]. A decrease in the erythrocyte concentration to 20% is considered not to affect the oxygen supply to the tissues [10].

The aim of this investigation was to study a combination of rheologic parameters of the blood during long- and short-term adaptation to muscular activity.

EXPERIMENTAL METHOD

The investigation was conducted on 16 adult mongrel male dogs weighing 14.5 ± 0.8 kg. Single periods of muscular activity (short-term adaptation) consisted of supporting a load of 40 and 80% of the maximal sustainable load (MSL) on the shoulder girdle. A load of 40% of MSL was supported for 1 h, i.e., it was of measured magnitude and duration, and was assessed as moderate. A load of 80% of MSL was applied to the limit (until the animal hung completely and often in the fixing straps). This was classed as a maximal load. Prolonged, i.e., lasting 8 weeks, training (long-term adaptation) was undertaken in two stages. For the first 4 weeks a load of 40% of MSL was used for 1 h daily, and during the next 4 weeks a load of MSL was applied. The blood and plasma viscosity was investigated by means of a capillary viscometer with four levels of assigned shear flow (230-270, 115-150, 33-54, and 13-20 sec^{-1}). The hematocrit index, hemoglobin concentration, and ESR were determined by the usual methods. Blood oxygen saturation was recorded by means of a cuvette oxyhemometer. The protein content and content of albumins and globulins were determined by the biuret method and the fibrinogen concentration by Rutberg's method. The degree of erythrocyte aggregation was estimated by microscopy of diluted blood [2]. The degree of deformability of the erythrocytes was established by analysis of the hematocrit index (the degree of "packing"), viscosity of the erythrocytes, and the coefficient of plasticity [8]. Blood for analysis was taken from a vein of the dog's hind limb. For statistical analysis of the data Student's test and correlation analysis was used and the informativeness of the parameters was determined by Kullback's test [1].

EXPERIMENTAL RESULTS

In the 8th week of training a reduction of blood viscosity was discovered at rest (Table 1): with different shear velocities it was 19.6-46.1% ($P < 0.01$). Under these conditions viscosity of the plasma also decreases significantly (11.2-19.0%, $P < 0.01$), but by a lesser degree than the viscosity of whole blood. The erythrocyte concentration decreased as a result of long-term adaptation by 18.2% ($P < 0.01$), and under these circumstances the degree of correlation between the hematocrit index and blood viscosity was reduced. The coefficient of correlation at the beginning of training was 0.710 and at the 8th week it was 0.648. The high degree of correlation between blood viscosity and hemoglobin level discovered in the initial period of adaptation also decreased toward the 8th week (the coefficients of correlation were 0.843 and 0.730 respectively). These facts indicate weakening

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TABLE 1. Rheologic Parameters of Blood during Single Muscular Activity in Course of Long-Term Adaptation (M ± m, n = 26)

Parameter	Before activity	After activity	P	Criterion of informativeness, bits
Initial period of activity				
Blood viscosity, cP				
Shear velocity, sec^{-1}				
10—18	6,81±0,40	9,20±0,64	<0,01	3,1
30—50	5,18±0,30	6,49±0,36	<0,01	4,6
100—130	3,65±0,10	4,12±0,016	<0,01	8,4
200—250	3,27±0,09	3,80±0,015	<0,01	10,7
Plasma viscosity, cP				
Shear velocity, sec^{-1}				
20	1,50±0,06	1,48±0,05	>0,05	1,0
270	1,26±0,02	1,25±0,01	>0,05	1,3
Hematocrit index, relative units	0,47±0,01	0,511±0,01	<0,01	14,6
Index of erythrocyte aggregation, relative units	0,114±0,01	0,143±0,030	<0,05	8,4
Viscosity of erythrocytes, cP	12,63±0,07	16,08±0,07	<0,01	3,7
Coefficient of hardness of erythrocytes	0,896±0,02	0,986±0,010	<0,01	1,7
Protein, g%	6,92±0,16	7,16±0,15	>0,05	0,2
Albumins, g%	4,91±0,29	5,46±0,23	>0,05	0,6
Globulins, g%	4,91±0,22	5,05±0,31	>0,05	0,2
Fibrinogen, relative units	9,03±0,44	8,40±0,35	<0,01	0,6
ESR, mm/h	2,46±0,24	1,17±0,34	<0,01	4,2
8th week of adaptation				
Blood viscosity, cP				
Shear velocity, sec^{-1}				
10—18	3,67±0,23	6,63±0,28	<0,01	6,2
30—50	3,22±0,21	5,35±0,35	<0,01	6,8
100—130	2,82±0,12	4,23±0,27	<0.01	13,4
200—250	2,63±0,15	3,90±0,23	<0,01	19,0
Plasma viscosity, cP				
Shear velocity, sec^{-1}				
20	1,22±0,04	1,26±0,06	>0,05	1,9
270	1,13±0,01	1,17±0,02	>0,05	1,4
Hematocrit index, relative units	0,399±0,06	0,484±0,018	<0,01	19,2
Index of erythrocyte aggregation, relative units	0,101±0,07	0,244±0,02	<0,05	12,7
Viscosity of erythrocytes, cP	6,71±0,18	11,60±0,31	<0,01	14,6
Coefficient of hardness of erythrocytes	0,830±0,030	0,810±0,030	>0,05	3,7
Protein, g%	6,94±0,20	7,47±0,16	>0,05	10,4
Albumins, g%	4,01±0,22	4,48±0,25	>0.05	0,3
Globulins, g%	6,12±0,18	5,90±0,28	>0,05	1,0
Fibrinogen, relative units	6,93±0.20	7,79±0,33	<0,05	2,2
ESR, mm/h	7,80±0,80	4,90±0,14	<0,05	6,6

of dependence of blood viscosity in adapted animals on the corpuscular component and they are linked with the phenomenon of a decrease in the degree of erythrocyte aggregation. This decrease amounted to 11.4% (Table 1). Correlation between blood viscosity and erythrocyte aggregation was weak, but at low shear velocities it was nevertheless higher than at high velocities (0.481 and 0.336 respectively). The high level of correlation of blood viscosity

with erythrocyte aggregation at low shear velocities confirms the view that if the velocity of the blood flow is low, aggregation makes the major contribution, whereas at high velocities the major role is played by deformation [12]. Reduction of the hematocrit index and internal viscosity of the erythrocytes and the decrease in the coefficient of plasticity of the erythrocyte membranes are evidence of an improvement in their deformability [8].

As a result of systematic training the fibrinogen concentration fell by 23% and that of albumins by 18.4% (Table 1). Blood viscosity in the initial period of training correlated with the protein level (coefficient of correlation 0.580), but in the 8th week the coefficient of correlation increased to 0.832. The fibrinogen concentration correlated with blood viscosity in the 8th week of adaptation more strongly than at the beginning of long-term adaptation. Consequently, a high degree of dependence of blood viscosity in trained animals on the plasma protein concentration was recorded. Dependence of blood viscosity on the protein level in the initial period was 25%, but in the 8th week of training it was 69%; correlation of viscosity and fibrinogen concentration was 31 and 73% respectively.

Consequently, during adaptation to muscular activity combined with a fall in blood viscosity, dependence of the latter on the erythrocyte factor diminishes whereas the influence of the protein component of the plasma increases.

A single period of muscular activity (short-term adaptation) was accompanied in the initial period of training by an increase of 20-30% in the blood viscosity (Table 1). Meanwhile viscosity of the plasma remained virtually unchanged by muscular activity. Changes in blood viscosity in adapted animals in response to activity were more marked than in untrained animals. The value of this index was 48.2% at high shear velocities and 81.1% at low. The absolute blood viscosity in trained animals during activity was 6.63 ± 0.28 cP, whereas in the initial period at rest it was 6.81 ± 0.40 cP. The integral value of viscous friction in adapted animals during activity was thus less than in unadapted animals at rest. A similar time course was observed on analysis of the hematocrit index. Although the peak to peak value of the response of the hematocrit index to activity was greater in trained animals, its absolute value was higher at the beginning of the training period. It can be concluded from the data described above that the fall in erythrocyte concentration follows a common trend with the fall in apparent blood viscosity during longterm adaptation to muscluar activity. All this increases the flowability of the blood by reducing the viscous resistance.

The high degree of correlation of blood viscosity and hemoglobin level (coefficient of correlation at rest 0.730, after activity 0.994) and also of blood viscosity and blood oxygen saturation (0.757 and 0.779 respectively) indicates close correlation between flowability of the blood and its oxygen transporting function.

Determination of Kullback's criterion of informativeness during analysis of the rheologic parameters showed that parameters such as the hematocrit index, hemoglobin level and blood oxygen concentration had 14.6, 2.8, and 5.9 bits of information at the beginning of training. Toward the end of the adaptive period these characteristics had 19.2, 6.6, and 13.4 bits of information. Analysis of criteria of informativeness of the protein components of the blood revealed an increase in the degree of informativeness in trained animals from 1.6 to 13.9 bits of information. When estimating short-term adaptive changes in a combination of rheologic parameters as a whole by criteria of informativeness it must be noted that the informativeness of all parameters was 63.4 bits, but in the 8th week of training it increased to 119.4 bits of information.

As a result of long-term adaptation to muscular activity an increase in flowability of the blood thus takes place, accompanied by hemodilution. The role of the erythrocyte component is reduced and that of the protein component is increased in determinacy of blood flowability of trained animals in this process.

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EFFECT OF EMOTIONAL-PAINFUL STRESS ON CONTRACTILITY OF THE HYPERTROPHIED MYOCARDIUM

A. I. Saulya, L. Yu. Golubeva, and F. Z. Meerson

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Compensatory hyperfunction and subsequent development of hypertrophy of the myocardium constitute the chief factor of compensation in heart diseases, hypertension, and other diseases of the circulatory system. However, after hypertrophy of the myocardium has reached a certain limit, it leads to a decrease in the functional capacity of the heart, which may go on to heart failure [1, 3]. Clinical experience shows that the breakdown of compensation in patients with marked hypertrophy of the heart is often due to infections, toxic conditions and, in particular, prolonged stress situations, which have themselves been shown capable of causing marked depression of contractility of the previously intact heart [5].

However, the question of how long-existing hypertrophy of the myocardium affects its resistance to stress-induced injury and, in particular, the degree of stress-induced depression of contractility, has not previously been studied.

The aims of this investigation were, first, to assess in more detail the contractility of the hypertrophied myocardium and study the effect of cations competing with Ca^{++} for its binding sites on cardiomyocyte membranes on contractility and, second, to discover how hypertrophy developing previously as the result of an experimental heart lesion affects resistance of myocardial contractility to injury by stress.

EXPERIMENTAL METHOD

Experiments were carried out on male Wistar albino rats weighing 150-170 g, divided into two groups. Rats of the main group were anesthesized with ether and their aorta constricted by application of a steel spring to its subdiaphragmatic segment by the method in [2]. A mock operation was performed on the control animals. Six months after the operation each group was divided into two subgroups; rats of subgroup 1 were subjected to emotional-painful stress (EPS), whereas rats of subgroup 2 remained intact.

EPS was produced by the method in [6] with exposure of 6 h. Contractility of strips of myocardium was studied 2 h after the end of exposure to stress, and also in intact animals, by the method described previously [5], the only difference being that the investigation was conducted only on strips of papillary muscle with an area of cross section under 1 mm^2 in which, according to data in the literature [1] hypoxia is not observed in the interior of the preparations.

The weight of the heart was determined by separate weighing [9], and showed that at the end of constriction of the aorta for 6 months the weight had increased to 1362 ± 10 mg com-

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