EFFECT OF VOLUME AND RATE OF BLOOD LOSS ON AUTOHEMODILUTION PARAMETERS

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Factors of extreme importance in the pathogenesis of posthemorrhagic disorders include the degree and rate of spontaneous replenishment of the circulating blood volume (CBV). This process takes place through the intervention of reserve powers, among which a definite role is played by the entry of tissue fluid into the blood stream — physiological hemodilution [10, 11, 12, 13]. According to data obtained in experiments in situ [12], the flow of liquid into the blood stream in the period of blood loss takes place at the rate of 0.055 ml/min/100 g body weight. A study of the mechanisms of this effect, also in experiments in situ, showed that the rate of entry of fluid into the blood during stimulation of sympathetic nerves or in response to the action of various vasoactive agents may vary from 0.017 to 0.3 ml/min/100 g [10, 12, 13].

The aim of this investigation was to study the effect of the volume and rate of blood loss and also of intravenous or intraintestinal infusions of a monomeric electrolyte solution (MES) on autohemodilution parameters.

EXPERIMENTAL METHOD

Experiments were carried out on dogs weighing 12-16 kg Under general anesthesia (Kalipsol, Relanium, diphenhydramine, 2 mg/10 kg body weight in each case) a transducer for impedanceometry was introduced via the femoral vessels into the aorta and catheters were introduced into the aorta and inferior vena cava. Blood loss amounting in volume to 20 or 30 ml/kg body weight, in one stage, at different rates — from 0.4 to 1 ml/min/kg. To obtain quantitative characteristics of the redistribution of fluid volumes between the extravascular and vascular sectors, the electrical impedance of the blood [4] and of the body [14] was determined. The diagnostic importance of determination of the basic impedance of the blood and body is that it correlates positively with the volume of fluid in the blood and tissues. Reduction of impedance of the blood and body indicates an increase in the volume of fluid in them, and vice versa [14]. Impedance of the blood was recorded by a specially developed impedance transducer [6]. The transducer, housed in the distal end of a catheter inserted into the aorta, was connected to a rheoplethysmograph, and calibrated before the investigation began. Tissue impedance was determined by the standard rheographic method. Ring electrodes were applied to the dog's fore- and hind limbs and connected in accordance with a tetrapolar derivation system. By comparing curves showing changes in resistance of the blood and tissue, recorded continuously throughout the experiment on the same tape, the dynamics of the process could be evaluated. The rate of entry of liquid into the blood or of its leaving the blood was calculated from the electrical resistance gradient of the blood by the equation:

$$-\Delta V_k = \frac{V_k}{\ln(Z_k/C)\cdot Z_{(k)}}\cdot \Delta Z,$$

where ΔV_k denotes the increase in circulating blood volume (in ml), V_k the circulating blood volume (in ml), Z_k the electrical resistance of the blood (in Ω), C is a parameter of the transducer (in Ω), and ΔZ_k indicates the increase in electrical resistance of the blood (in Ω).

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TABLE 1. Changes in Volemic Parameters 30 min after Blood Loss of Varied Severity, at the Rate of 0.6-0.7 ml/min/kg, and also after Blood Loss Combined with Infusion of Solution into Small Intestine

Conditions	Circulating blood volume, ml/kg	Circulating plasma volume, ml/kg	Circulating plasma proteins, g/kg	Replacement of deficit by autohemodilution, %	
				circulation plasma volume	OUK
After blood loss in volume of:					
Initial data (n = 42)	79,1±2,0	43,5±1,6	2,45±0,08	—	—
20 ml/kg (n = 17)	65,0±2,0*	38,1±1,0*	1,64±0,06*	54	30
30 ml/kg (n = 13)	56,2±1,5*	32,5±0,71*	1,35±0,06*	39	23
After intra-intestinal infusion of solution during blood loss in a volume of:					
20 ml/kg	80,0±2,4**	53,6±1,6**	2,20±0,04**	123	100
30 ml/kg	70,6±1,9**	48,7±1,4**	1,56±0,06	110	80

Legend. *) Significance of differences from initial data, **) significance of differences from data obtained after blood loss in corresponding volume.

TABLE 2. Individual Differences in Changes in Autohemodilution Parameters at Successive Stages of Blood Lossin Total Volume of up to 30 ml/kg (results of individual experiments)

Rate of blood loss, ml/min/kg	Volume of blood loss, ml/kg	Rate of movement of interstitial fluid into blood stream, ml/kg/min	Volume of interstitial fluid moving into blood stream, ml/kg	Replacement of volume of blood loss by autohemodilution, %
Dog No. 1				
0,60	4,8	0,166	1,33	28
0,60	14,4	0,189	4,53	31
0,60	25,2	0,157	6,63	26
0,60	30,0	0,150	7,37	24
Dog No. 2				
0,64	8,2	0,201	2,61	31
0,64	14,6	0,182	4.22	29
0,64	24,2	0,158	6,04	25
0,64	30,0	0,177	8,35	27
Dog No. 3				
1,06	2,1	0,178	0,36	17
1,06	5,3	0,194	0,97	18
1,06	14,9	0,212	2,97	20
1,06	20,0	0,212	4,02	20
Dog No. 4				
0,87	2,6	0,541	1,62	62
0,87	9,5	0,493	5,40	56
0,87	23,4	0,522	14,15	60
0,87	33,0	0,494	18,50	56

Legend. Blood loss from dog No. 4 took place 15 min after intraintestinal infusion of 200 ml of MES.

Initially and in the course of blood loss CBV was determined by the impedance method [7], the blood hematocrit (Ht) was obtained, and the total serum protein concentration was determined by the biuret method. In some experiments before and during blood loss an infusion of MES was given either intravenously or by the intraintestinal route through a previously formed duodenal fistula [5]. Altogether 30 experiments were carried out on 30 dogs.

EXPERIMENTAL RESULTS

The results of analysis of the experimental data are given in Tables 1 and 2. Blood loss at the rate of 0.4-1 ml/min/kg was accompanied by an increase in electrical resistance of the body and a decrease in electrical resistance of the

blood, evidence of the movement of liquid from the tissues into the blood stream. Analysis of the impedanceometry curves showed that the entry of fluid into the blood began on average 13 sec after the beginning of blood loss. Movement of the liquid was not uniform in volume, and took place by a pulsating flow with average velocity of 0.186 ± 0.020 ml/min/kg (0.15-0.22 ml/min/kg) (Table 2). The changes in the rate of autohemodilution did not depend significantly on the rate of blood loss. As a result, the slower the rate of blood loss, the more complete the spontaneous correction of hypovolemia during the period of blood loss: on average 43% of its volume with blood loss at the rate of 0.4 ml/min/kg, 28% at a rate of 0.6 ml/min/kg, and 19% at the rate of 1 ml/min/kg (Tables 1 and 2).

With an increase in volume of blood loss to 15-20 ml/kg the rate of autohemodilution in individual experiments increased by 10-26% of the initial values, but with a further increase in volume of blood loss to 30 ml/kg, it fell again to the initial values (Table 2). On average, however, no significant correlation could be found between changes in the rate of autohemodilution and the volume of blood loss ($r = -0.42$). Meanwhile, the investigations revealed a linear relationship between the volume of blood loss to 30 ml/kg and the volume of tissue fluid moving into the blood stream ($r = -0.84$) (Table 2).

The study of autohemodilution in the posthemorrhagic period showed that termination of blood loss was accompanied immediately by a considerable reduction in the mobilization of extravascular fluid. On average the rate of autohemodilution was reduced by 30% to 0.13 ml/kg/min. However, after 10-15 min of the posthemorrhagic period the rate of autoperfusion fell even more and the volume of incoming blood was reduced to a minimum.

In the next group of experiments the effect of intraintestinal or intravenous infusion of MES on reabsorption of fluid induced by blood loss was studied.

The experiments showed that despite the movement of fluid into the blood stream as a result of its absorption from the intestinal lumen or as a result of the intravenous infusions, in both cases the mobilization of interstitial fluid took place immediately after the beginning of blood loss. As a result, the rate of autohemodilution increased and an increase in the volume of fluid moving into the blood stream was observed (Table 2), thereby restoring the initial CBV (Table 1). As the investigation showed, fluid entering the internal medium following resorption from the intestine did not leave the blood stream for the next few hours.

The results of the study as a whole fully confirm the established view that the trigger mechanism aimed at mobilizing extravascular fluid is neurohumoral in nature [8, 10]. That this is so is shown both by the rapid response of the body to the beginning of blood loss and, in particular, to its ending, and also by the active autoperfusion during the course of blood loss. The phylogenetic origin of this regulatory mechanism is shown by the fact that mobilization of the extravascular fluid in our experiments took place in response to blood loss even when normovolemia was maintained artificially by intravenous or intraintestinal infusion of MES.

The results of the investigation showed that our calculated data on the rate of movement of fluid from the tissues into the blood are perfectly comparable with the results of investigations by other workers [12]. The small difference between the values of the parameters can be attributed to significant differences in the technique used.

The rate of physiological hemodilution accompanying blood loss in a volume of 20-30 ml/kg was shown to vary within a narrow range of values (0.15-0.22 ml/kg/min) and to depend only a little on the rate of blood loss. It can be tentatively suggested that the basic mechanism canceling out the effect of the rate of blood loss on the rate of movement of fluid into the blood is the functional interdependence of the system of factors determining the direction and velocity of flow This system of factors, interacting in accordance with the multiple feedback principle, regulates the exchange of fluid between blood and tissues [3].

Since the rate of blood loss has little effect on the rate of autohemodilution, the volume velocity of the flow of fluid from tissues into blood is virtually identical with both fast and slow blood loss of the same volume, but the slower the blood loss, the more fully is the degree of hypovolemia restored. Thus it is the rate of blood loss which determines the efficacy of an important adaptive mechanism aimed at spontaneous replenishment of the CBV deficit such as autohemodilution.

Our results conclusively showed that the process of absorption from the intestine is also a powerful physiological regulator of the volemic status of the body. Evidently this is due to the fact that it is in the course of absorption of water, electrolytes, and monomers, and also the inflow of endogenous proteins, including those synthesized by the intestinal wall [1], into the blood stream that a structurally organized basic substrate of volemia is formed, namely water—protein—electrolytes [2], maintaining the water-retaining property of the plasma and thereby determining the efficacy of enteral infusions.

Thus our data provide a theoretical basis for the use of enteral infusions in order to correct hypovolemia.

The results of our previous investigations showed that the resorptive activity of the intestine during the 30 min immediately after blood loss, up to 40 ml/kg (at the rate of 0.7 ml/min/kg) is completely preserved and maintains the movement of MES into the internal medium at an average rate of 0.54 ml/kg/min. The present investigation showed that the process of absorption of fluid from the intestine does not block its movement from the interstitial tissue, and these two flows together greatly increase the volume of physiological hemodilutions. As a result, intraintestinal infusion of MES of a certain composition, given during blood loss or thereafter, but in the period of preservation of the absorptive function of the small intestine, can prove to be an effective way of making good the plasma deficit.

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