THE RATIO OF ERYTHROCYTES TO PLASMA IN THE CIRCULATING BLOOD DURING EXTERNAL CARDIAC MASSAGE

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External cardiac massage is the most important of the many methods of resuscitation [2]. However, if it is carried out for a prolonged period, circulatory disturbances arise, the mechanism of which is still incompletely understood. In particular, the ratio of erythrocytes to plasma in the circulating blood is altered, as indicated by the hematocrit reading on arterial blood [12].

The distribution of erythrocytes in the vascular bed under normal conditions is unequal: the level decreases in the smaller caliber vessels [5]. The highest hematocrit readings are observed in the sinusoidal vessels of the spleen and the lower readings in the great arteries and veins; the lowest are in the small vessels and capillaries. Thus, the mean percent content of erythrocytes in the whole circulating blood (the so-called somatic or circulatory hematocrit index) is always less than in the great arteries and veins. Therefore, the relationship of the circulatory hematocrit index to the hematocrit index of the great vessels is significantly less than one (0.91 for man and 0.9 for the dog [8]). This coefficient [4] (f_1, or F-cells) is constant if the ratio of erythrocytes and plasma in the various compartments of the vascular bed is not altered. With abrupt disruption in hemodynamics (shock, massive hemorrhage) a significant decrease in the coefficient f_1 is noted and this indicates a shift in the regular elements of the blood between the smaller and large vessels [8].

The erythrocyte content in the great vessels may increase under the influence of various factors: the absolute increase in mass of circulating red cells, decrease of circulating plasma volume or redistribution of red cells in the vascular bed.

We did not find an explanation in the literature of why the hematocrit index increases in the arterial blood during external cardiac massage. At the same time the elucidation of this problem represents both theoretical and practical interest, since it permits some approach to understanding the characteristics of the hemodynamics during cardiac massage and to developing measures to increase the effectiveness of this method.

We set out to establish how the ratio of erythrocytes to plasma is altered and what basic principle exists for these changes during external cardiac massage. With this goal in mind we determined the volume of the circulating blood, the erythrocyte mass and the total plasma content, as well as the arterial blood hematocrit reading and the ratio of the circulating hematocrit reading to the arterial one.

EXPERIMENTAL

The experiments were performed on 14 dogs weighing 12.5 to 21 kg. They last received food 24 h prior to the experiment. With light pantopone-thiopental anesthesia (miotic pupils, active corneal reflexes), after a 30-32 min control period ventricular fibrillation was induced with an alternating current from an illuminating grid with voltage 127 V. After a two minute wait, blood circulation was initiated by external cardiac massage by pressing (70-110 times per min) with the proximal part of the palms on the lower third of the thorax. At the same time artificial respiration with room air was given via an endotracheal tube using an RPR respirator ("Pesty" brand) (inspiratory

Circulating Blood Volume (VCB), Circulating Red Cell Mass (RCM), Circulating Plasma Volume (VCP), Arterial and Circulating Hematocrit Indices, and Coefficients in the Control Period and After 15 Minutes of External Cardiac Massage (average of 11 experiments)

Time at which blood sample taken	VCB	RCM	VCP	Hematocrit index		Coefficient f_1
	in ml/kg			arterial	circulating	
After 15 min of control period	80,68 ±3,28	37,85 ±1,46	42,83 ±2,14	46,72 ±1,19	46,97 ±0,88	0,99 ±0,01
After 15 min of external cardiac massage	72,44 ±3,23	31,23 ±1,54	41,21 ±2,14	51,18 ±1,39	43,15 ±1,79	0,85 ±0,03
P	<0,01	<0,01	<0,05	<0,01	<0,01	<0,01

volume 30 ml/kg, rhythm 16-18 times per min). In some of the experiments noradrenalin in fractional doses (0.2 ml) was injected into the right jugular vein to increase the effectiveness of the cardiac massage. At the end of a given period of massage (30 min) spontaneous cardiac activity was restored by using condenser discharge impulses of 3000-4500 V on the intact chest wall (according to the method of N. L. Gurvich). In a number of instances of "slow" fibrillation, which indicated myocardial hypoxia, a preliminary arterial injection of small amounts of polyglucine (30-50 ml) with the addition of adrenaline, noradrenaline or sometimes potassium chloride, was used to improve defibrillation. During the experiment the arterial pressure, pulse, respiration and changes in venous pressure were recorded on the slow kymograph, the ECG was recorded on standard leads on a six channel electropolygraph ("Al'var" make).

The circulating red cell mass was measured by using cells labelled with the radioactive isotope Cr^{51}, according to the method of Gray and Sterling [6] as modified by N. N. Chernysheva [3], introducing the cells in the control period and after one minute of cardiac massage (after taking a "baseline" blood sample). The circulating plasma volume was measured with Evan's blue dye (T-1824) according to the method of Gregerson and Stewart [7] as modified by Surtshin and Rolf [11]. Labelled erythrocytes and Evan's blue were injected into the right jugular vein. Blood samples were taken from the left femoral artery at 15, 20 and 30 min after the injection both in the control period and during cardiac massage. In all samples the hematocrit index was measured by centrifugation of the blood in graduated capillary tubes for 55 min at 3000 rpm. The "mean" hematocrit index for the total circulating blood was calculated according to the formula [4]

$$\text{Circulating hematocrit index} = \frac{\text{RCM} \times 100}{\text{RCM} + \text{VCP}}$$

where RCM = circulating red cell mass; VCP = volume of circulating plasma. For calculation of the coefficient f_1 we used the formula

$$f_1 = \frac{\text{Circulating hematocrit index}}{\text{Arterial hematocrit index}}.$$

All observations (14 experiments) were divided into two groups. In the first group (3 experiments) the degree of fluctuation in the circulating and arterial hematocrit indices and their ratio (f_1) were determined, as well as the circulating blood volume, red cell mass and total plasma volume at control conditions. The duration of the experiment and the time of introducing the indicators and removing blood samples were the same as in experiments with cardiac massage. Statistically negligible decreases in arterial hematocrit index, f_1 coefficient, circulating blood volume, red cell mass and plasma volume were found. It is possible that the changes found were caused by the blood loss with the samples (2-3 ml/kg by volume) or were within limits of error for the methods used.

In the second group (11 experiments) at the end of the control period (after the two minutes sudden arrest of blood circulation) external cardiac massage was carried out, and the same indices as in the first group of experiments were studied in the dynamic situation. In all experiments the level of systolic arterial pressure produced by the massage reached 40-60 mm. During the first 15 min of massage "active" ventricular fibrillation was noted (fibrillatory rate 500-600 per min, amplitude greater than one millivolt) and the corneal reflexes and spontaneous respiration were preserved. During the massage process the hematocrit index of the arterial blood rose significantly; simultaneously the circulating hematocrit index and f_1 coefficient decreased (see table). A marked decrease in the circulating blood volume and circulating red cell mass was observed. The indicated changes considerably exceeded the limits of normal variability found in animals of the control group. The volume of circulating plasma decreased to a small degree during massage.

Thus, in our experiments with external cardiac massage, we noted an increase in the hematocrit index of arterial blood, which is in accord with data in the literature [12]. This increase cannot be connected with the exit of red cells from the blood depots (in particular, from the spleen), since the investigations we performed showed that the circulating red cell mass decreases during cardiac massage. Plasma loss also could not be the decisive factor because the circulating plasma volume is not significantly diminished. At the same time we observed a decrease in the f_1 coefficient, which may be explained mainly by the redistribution of the regular elements of the blood from the small vessels to the larger.

On this basis we can conclude that the increase in hematocrit index during cardiac massage is produced by the basic centralization of the blood circulation, i.e., the transfer of a considerable quantity of red cells from the small vessels to the large. In the literature there are data concerning the state of the peripheral circulation during shock and terminal states, which indicate that with abrupt disturbances in the circulation a paucity of erythrocytes is observed in a number of organs and tissues [9]. In addition there is indication that blood is deposited in different areas of the capillary bed (red cell aggregates) leading to a decrease in the total circulating red cell mass [1, 5]. Evidently both this and other mechanisms of disturbance in the peripheral circulation occur during cardiac massage.

Our data confirm the opinion of other authors [10] that during abrupt or acute alterations of hemodynamics the hematocrit index and the blood volume are regulated independently of one another. Therefore, for exact measurement of the blood volume under these circumstances it is impossible to use the hematocrit index and at the same time mark one of the fractional blood volumes. It is necessary to mark both erythrocytes and plasma at the same time.

Because the volume of circulating blood diminishes during cardiac massage (mainly as the result of a decreased circulating red cell mass, and in lesser degree because of decreased plasma) then to raise the effectiveness of external cardiac massage it is probably advisable to transfuse with whole blood during the massage. The amount of transfused blood evidently should be about 8.24 ml per kg of body weight, since it is precisely by this value that the circulating blood volume decreases during external cardiac massage.

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