sulin–glucocorticoid balance, reflecting the adaptive character of the metabolic responses. From this standpoint, the study of the insulin depot function of the erythrocytes after CCT provides indirect evidence of the degree of metabolic adaptation of the body at different stages of the posttraumatic period.

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ROLE OF K^+, Na^+, AND Ca^{++} IONS IN THE CARDIODEPRESSOR ACTION OF BLOOD PLASMA IN BURN SHOCK AND THE CRUSH SYNDROME

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KEY WORDS: blood plasma; K^+, Na^+, and Ca^{++} ions; burn shock; crush syndrome; myocardium; intracellular action potentials; isometric contractions.

Burn shock and the crush syndrome (CS) are accompanied by changes in the ionic composition of the blood plasma, expressed as an increase in K^+ and a decrease in Na^+ concentration [5, 6, 9, 11]. In burns an increase in the Na^+ concentration also is observed [1]. A decrease in the Ca^{++} concentration has been found in CS [4]. Recently the direct cardiodepressor action of blood plasma in burns and CS has been demonstrated [2, 7]. There is reason to suppose that changes in the ionic composition of "burn" and "CS" plasma may affect its cardiodepressor action, because we know that elevation of the K^+ or depression of the Ca^{++} concentration in the extracellular solution inhibits contractility of myocardial preparations [10, 12].

In this investigation the K^+, Na^+, and Ca^{++} concentrations were determined in blood plasma of burned animals and animals with CS. The ionic composition of the blood plasma of intact animals was measured and concentrations of the ions were established at levels corresponding to those of "burn" and "CS" plasma. The action of normal blood plasma with an artificially changed ionic composition on intracellular potentials and isometric contractions of isolated rabbit heart papillary muscles was then studied. The aim of the investigation was to discover to what extent changes in myocardial contracility in burns [2] and CS [7] are linked with disturbance of the ionic composition of the blood plasma.

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TABLE 1. Ionic Composition of Blood Plasma (mM) after Burns

Statistical index	K^+	Na^+	Ca^{2+}
Before burning			
M	3,06	131,6	1,18
$\pm m$	0,23	3,35	0,12
$\pm\sigma$	0,73	10,72	0,40
n	10	10	10
20 min after burning			
M	5,28	131,4	1,14
$\pm m$	0,83	2,67	0,12
$\pm\sigma$	2,65	8,43	0,37
n	10	10	10
P	<0,02		
1 h after burning			
M	4,61	131,7	1,06
$\pm m$	0,38	2,77	0,11
$\pm\sigma$	1,05	7,75	0,31
n	8	8	8
P	<0,01		

Legend. Here and in Table 2, if no value of P is given this implies that the parameter does not differ significantly from its initial value.

TABLE 2. Ionic Composition of Blood Plasma (mM) in CS

Statistical index	K^+	Na^+	Ca^{2+}
Before decompression			
M	3,42	140,6	1,18
$\pm m$	0,37	6,1	0,17
$\pm\sigma$	1,03	17,07	0,48
n	8	8	8
1.5 h after decompression			
M	4,92	139,7	1,20
$\pm m$	0,46	6,08	0,17
$\pm\sigma$	1,29	17,01	0,48
n	8	8	8
P	<0,05		
3 h after decompression			
M	5,12	135,8	1,45
$\pm m$	0,93	10,3	0,22
$\pm\sigma$	1,86	20,61	0,44
n	4	4	4
P	<0,05		

EXPERIMENTAL METHODS

Experiments were carried out on Chinchilla rabbits anesthetized with urethane (1 g/kg, intravenously). There were five series of experiments. In series I (10 rabbits) and II (eight rabbits) concentrations of K^+, Na^+, and Ca^{++} ions in blood plasma were investigated in burns and CS respectively. In series III and IV isometric contractions and the intracellular transmembrane potentials were studied in response to electrical stimulation of isolated papillary muscles of the heart, during perfusion with plasma from animals with burn

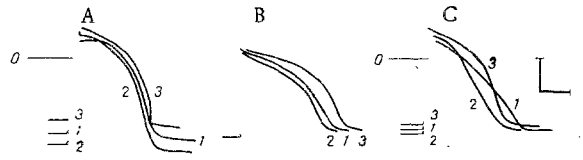

Fig. 1. Action of control (A), "burn" (B), and "CS" (C) blood plasma on intracellular potentials of papillary muscles from rabbit heart. A: 1) Tyrode solution, 2) control plasma (K^+ = 2.3 mM), 3) the same (K^+ = 7.8 mM); B, C: 1 and 2) the same as in A, 3) "burn" and "CS" plasma, respectively. 0) Line of zero potential; horizontal lines on left mark RP level. Calibration: vertically 25 mV, horizontally 50 msec.

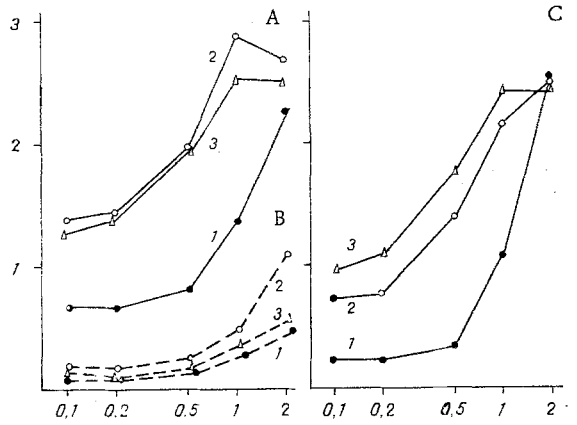

Fig. 2. Changes in frequency-strength of contraction relations in papillary muscles of rabbit heart under influence of raised K^+ concentration in control blood plasma. Abscissa, frequency of stimulation (Hz); ordinate, strength of contractions (in g). 1) Tyrode solution, 2) control blood plasma: A) K^+ = 2.5 mM, B) K^+ = 2.2 mM, C) K^+ = 2.3 mM; 3) blood plasma with increased K^+ concentration: A) K^+ = 6 mM, B) K^+ = 7.8 mM, C) K^+ = 5.6 mM.

shock (16 experiments) and CS (14 experiments). In series V (3 experiments) electrical activity and contractility of the papillary muscles were investigated during perfusion with blood plasma from control animals with artificially modified ionic composition, corresponding to the greatest changes observed in it in burn shock and CS.

Blood for perfusion of the papillary muscles and for determination of K^+, Na^+, and Ca^{++} concentrations was taken from the carotid artery. In the series of experiments with burn trauma blood samples for determination of ionic composition were taken before burning (30-35% of body surface, scalding by water with a temperature of 100°C for 1 min) and 20 min and 1 h after the experiment. In the series of experiments with CS [compression (90 kg) of the soft tissues of the thigh for 12 h] blood samples for determination of ionic composition were taken before and 1.5 and 3 h after decompression. The blood was collected into heparinized centrifuge tubes. Plasma was obtained from the blood by centrifugation for 20 min at 6000 g. Concentrations of free K^+, Na^+, and Ca^{++} ions in the plasma were determined by means of ion-selective electrodes, included in the kit of the pH M-64 (Radiometer, Denmark) pH-meter. Isolation of the papillary muscles, their arrangement in the working chamber, the apparatus used, and the composition of the Tyrode solutions were described previously [2]. Contractility of the papillary muscles was recorded during successive change of frequencies of stimulation: 0.1, 0.2, 0.5, 1, and 2 Hz. In the experiments of series III and IV the order of perfusion of the myocardial preparations was as follows: Tyrode solution, blood plasma from control animals, blood plasma from animals with burn trauma or CS. In series V the

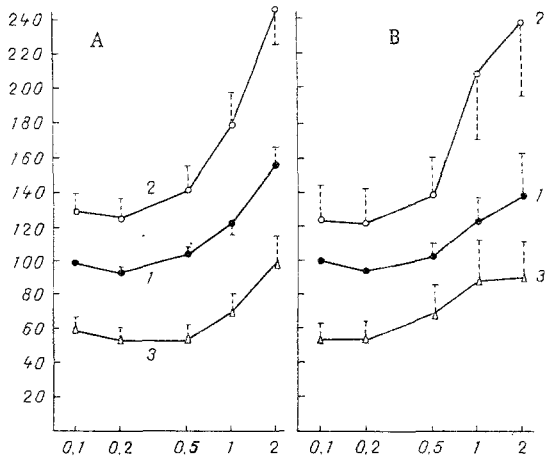

Fig. 3. Effect of "burn" (A) and "CS" (B) blood plasma on frequency versus strength of contraction relations in papillary muscles of rabbit heart. Abscissa, frequency of stimulation (in Hz); ordinate, amplitude of contractions (in %). Amplitude of contractions in Tyrode solution with frequency of stimulation of 0.1 Hz corresponds to 100%. 1) Tyrode solution, 2) control plasma, 3) "burn" and "CS" plasma, respectively.

order of perfusion was: Tyrode solution, blood plasma of control animals, blood plasma of control animals with modified ionic composition. The plasma was diluted with Tyrode solution in the ratio of 1:1. To prevent the plasma from frothing during oxygenation, "Antifoam" antifrothing agent was used.

EXPERIMENTAL RESULTS

Data on the change in ionic composition of the plasma from animals with burn shock and CS are given in Tables 1 and 2. For practical purposes only the K^+ ion concentration changed. The free K^+ concentration in the plasma in eight of 10 cases 20 min after burning was 100-180% of the initial values, in two experiments the K^+ concentration rose sharply (258 and 276%). On average the K^+ concentration 20 min after burning was increased from 3.06 ± 0.23 to 5.28 ± 0.83 mM. During the next 40 min of observation no significant changes took place in this parameter. In CS, in seven of eight cases the K^+ concentration in the plasma 1.5 h after decompression was 110-160% of the initial values, and in one case it reached 212%. On average the K^+ concentration 1.5 h after decompression was increased from 3.42 ± 0.37 to 4.92 ± 0.46 mM. The ionic composition of the plasma of animals with CS, incidentally, did not differ significantly from the control before decompression. No statistically significant changes in the free Na^+ and Ca^{++} concentrations could be found in the "burn" and "CS" plasma in the models of burn shock and CS used. The initial Ca^{++} concentration in normal blood plasma varied in different animals from 0.65 to 2 mM, and the Na^+ concentration from 112.0 to 147.0 mM.

Changes in the shape and amplitude of intracellular action potentials (AP) under the influence of the control plasma (K^+ = 2.3 mM) and with an increase in the K^+ concentration in the plasma to 7.8 mM are shown in Fig. 1A. Normal plasma increased the original resting potential (RP) and shortened the duration of AP compared with that in Tyrode solution. Plasma with an increased K^+ concentration, on the other hand, reduced RP of the myocardial fibers and increased the duration of AP. Changes in the shape and amplitude of AP under the influence of "burn" and "CS" plasma are illustrated in Fig. 1B, C. Like control plasma with an increased K^+ concentration, the "burn" and "CS" plasma considerably increased the duration of AP. It can be tentatively suggested that this effect of the "burn" and "CS" plasma was due to K^+ ions.

The character of changes in frequency versus strength of contraction relations in the papillary muscles of the rabbit heart during an increase in the K^+ concentration up to 5.6-7.8 mM is shown in Fig. 2, which gives the results of three different experiments. With an increase in the K^+ concentration by 3.3-5.6 mM the amplitude of isometric contractions within

the range of frequencies of stimulation from 0.1 and 2 Hz was reduced negligibly in two experiments, and in one experiment it was actually increased compared with the amplitude of contractions in plasma with a normal K^+ concentration.

Perfusion of the papillary muscles with "burn" or "CS" blood plasma caused a sharp decrease in amplitude of the isometric contractions in all experiments. Changes in frequency versus strength of contraction relations in the papillary muscles of the rabbit heart under the influence of "burn" and "CS" plasma are illustrated in Fig. 3.

It was thus found that raising the K^+ concentration in blood plasma of normal animals up to the maximal values recorded in "burn" and "CS" plasma caused an increase in the duration of intracellular AP similar to that found in blood plasma of animals in a state of burn shock or CS. Increasing the K^+ concentration in the plasma reduces the potassium concentration gradient for the outward flow of K^+ ions from the cell in the period of development of the repolarization phase and is the cause of the increase in duration of AP. These changes in the duration of the intracellular AP evidently lie at the basis of ECG disturbances found in the early stages of burn shock [3] and CS [8].

The fall in amplitude of isoelectric contractions of the papillary muscles recorded in these experiments under the influence of "burn" and "CS" plasma was much more marked than in control plasma with an increased K^+ ion concentration, in which the negative inotropic action action of the plasma was virtually absent.

Hyperkaliemia is thus not the main cause of disturbance of cardiac contractility in burn shock and CS.

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