THE EFFECT OF POTASSIUM ON THE CORONARY CIRCULATION

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A normal potassium ion concentration is of great importance for cardiac activity and blood vessel tonus. Increase in the blood potassium ion, according to the majority of investigators, leads to the constriction of peripheral vessels [2, 10, 19], however certain authors describe its action as vascular dilatation [7].

Recently a connection has been established between pathological EKG changes during myocardial infarction and migration of potassium ions into the heart muscle—their exodus from the zone of necrosis, accumulation in the border zone,and increased concentration in the blood [4, 8, 13]. On the other hand, when potassium chloride is given intravenously [22], its introduction into the coronary artery [12, 18], pericardium,or epicardium [20] temporarily causes EKG changes similar to those observed during myocardial infarction. When a necrotic piece of muscle tissue is apposed to a frog heart a monophasic electrogram appears [5], which phenomenon (as shown on rabbit heart) is connected with the egress of potassium ion from the damaged tissue into the undamaged myocardium [4].

In these papers, simultaneous registration of EKG and changes in the coronary blood flow during the action of potassium chloride was not done and it has not been established if there is an essential correspondence between these indices. There is a limited number of studies on the question of the effect of potassium on the tone of the coronary vessels, carried out on isolated, fibrillating hearts. Some authors have noted a dilatation of coronary vessels in response to the injection of small doses and constriction of biphasic reaction when large doses of potassium chloride are given [14-16]; others find only coronary dilatation independent of dosage [9, 11, 17]. The effect of an increased potassium concentration in the entire circulatory bed on the tone of the coronary vessels has not been studied, or the importance of applying different concentrations of KCL to the epicardium.

The investigations we carried out studied the changes in coronary circulation in the intact organism after injection of KCl into the systemic circulation, the coronary vessels and after applying KCl to the epicardium.

METHODS

The experiments were performed on 55 dogs of weight 14-20 kg under morphine-urethane anesthesia. Circulatory depression of the heart was studied by the method of thermoelectric registration of the volume velocity of the blood flow in the circumflex branch of the left coronary artery [1] and by the method of resistography, i.e., by registering changes in pressure in the coronary vessels under a constant volume of blood entering them [6]. In the latter case, the blood was taken from the carotid artery and returned via a perfusing pump into the circumflex branch of the left coronary artery through a cannula inserted into it. Intra-coronary injection of KCl solutions were done throught the perfusion pump system through a triple valve. The application of a tampon soaked in KCl solution was made to the anterior surface of the heart and in some of the experiments also to the region supplied by the arteries (the tampon had an area of three cm^2 and was placed under the pericardium). The length of the application in experiments with perfusion was 1-2 min, and in experiments with thermoelectric method, 5-10 minutes. Circulatory supply of other organs was recorded with vascular thermoelectrodes or needles of the Gibbs type. Almost all experiments were carried out with artificial respiration. In many experiments the EKG was recorded on the standard leads.

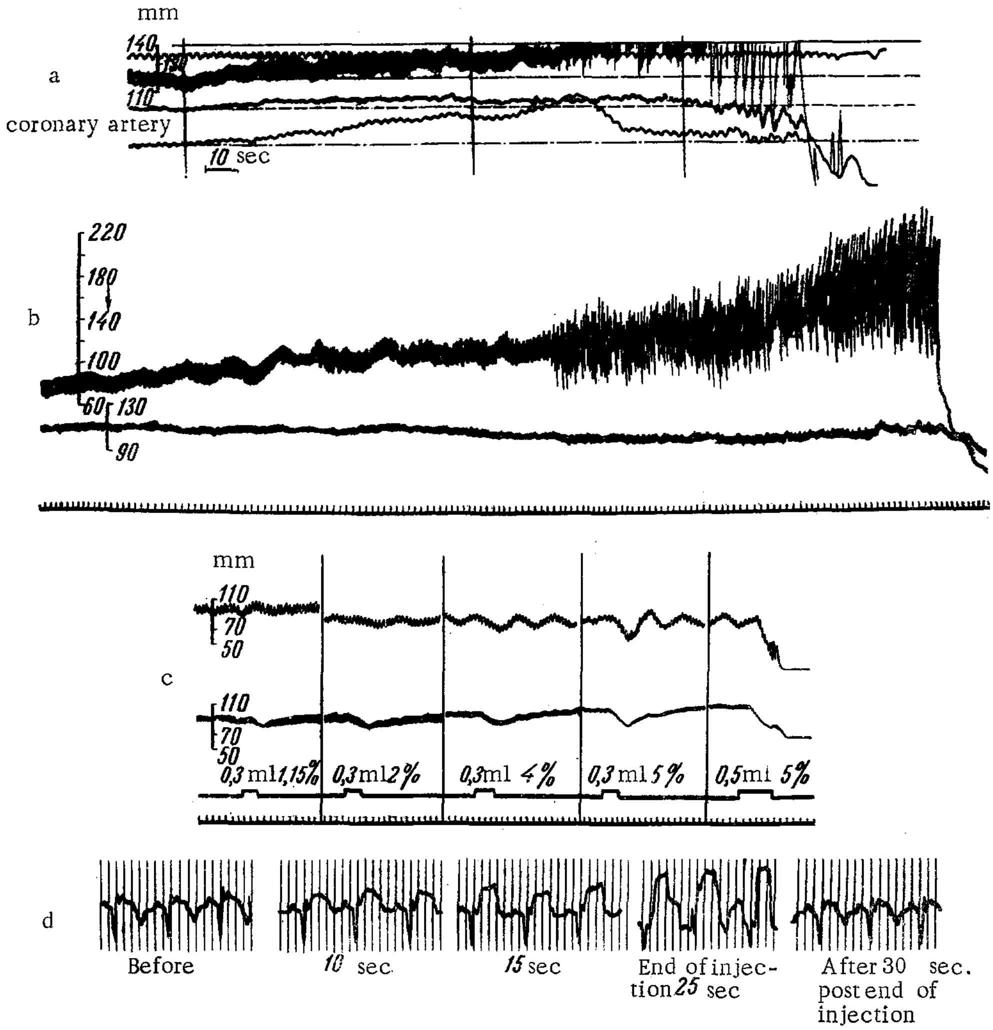

Fig. 1. Effect of Intravenous (a and b) and Intracoronary (c and d) Injection of KCl on Coronary Vessel Tone (b and c), Volume Velocity of Coronary Blood Flow (a) and EKG (d). Meaning of curves (from top down): a) respiratory movements, blood pressure, rate of blood flow in coronary and renal arteries; first vertical line—beginning of KCl injection; b) blood pressure, perfusion pressure in coronary artery, time marks (5 sec), arrow—beginning of injection of solution; c) blood pressure, perfusion pressure after injection of different concentrations of KCl, mark of injection, time marks (5 sec); d) EKG after intracoronary injection of 1.15% KCl solution.

RESULTS

After intravenous administration of various concentrations of KCl (one, 1.5, two, three and 5%; dose 250-100 mg) an increase in coronary blood flow was invariably observed. When the KCl concentration was significantly increased, cardiac standstill occurred. In a portion of the experiments considerable arrhythmia developed prior to cardiac standstill, and during the arrhythmia coronary flow decreased (Figure 1, a). When isotonic KCl (1.15%) was injected very slowly the changes were less marked, but were not altered in character, i.e. a slight increase in blood flow was observed which fell during arrhythmia. It follows from experiments using constant volume perfusion of the coronary arteries that the increase in coronary blood flow is related not only to the increase in total arterial pressure but also to the decreased coronary vessel tone (Figure 1, b).

Injection of KCl directly into the coronary artery produced a fall in coronary vessel tone in all concentrations used in doses of 3.4-17 mg. When 0.5 ml of 5% solution (25 mg KCl) was injected, cardiac arrest always resulted (Figure 1, c). Only in one out of 10 experiments when KCl was injected in large concentration was a biphasic reaction observed. The EKG changes after intra-coronary injection were similar to those observed in myocardial infarction; they disappeared after injection was stopped (Figure 1, d).

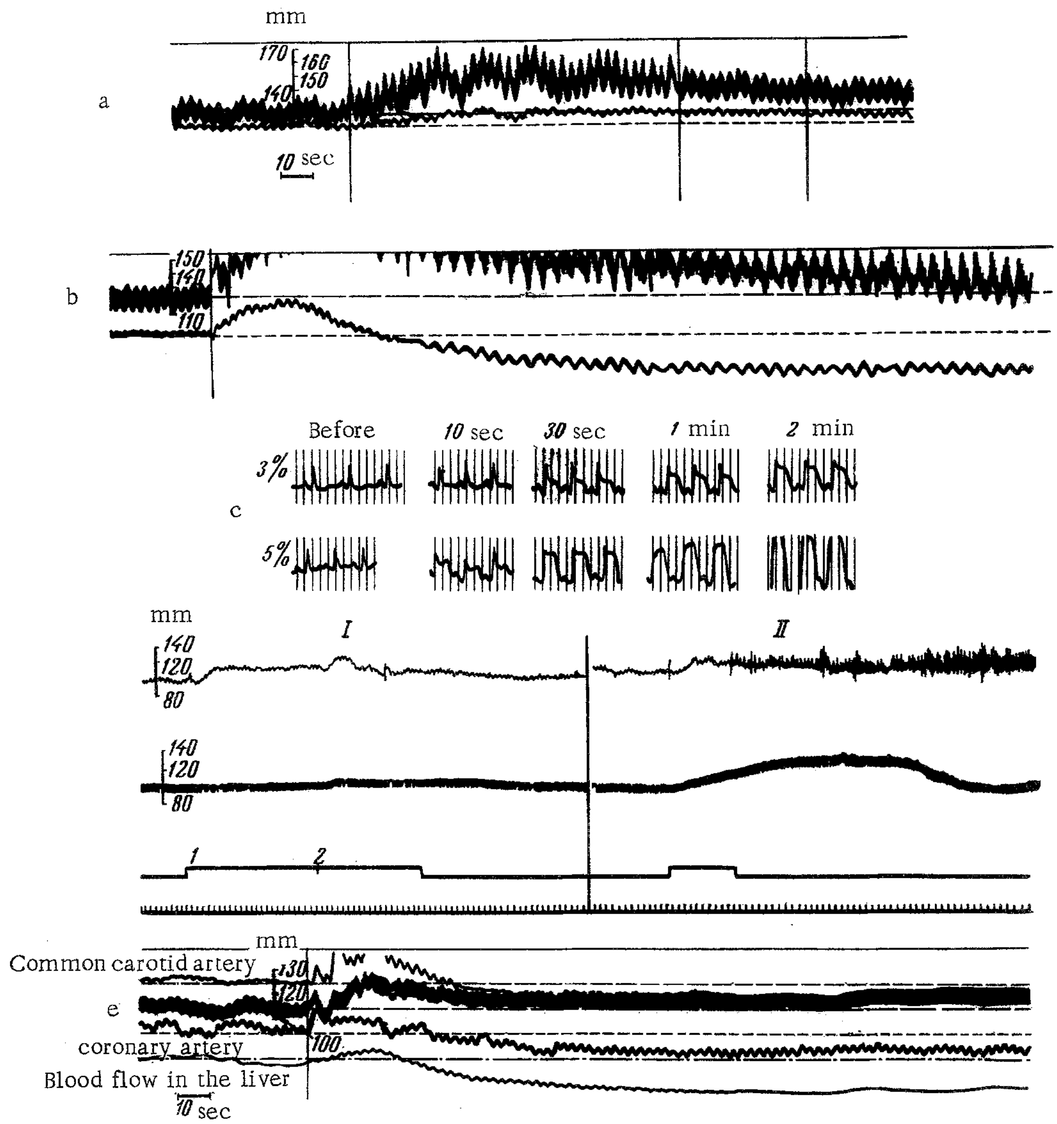

Fig. 2. Changes in volume velocity of blood flow (a, b, e), perfusion pressure in coronary vessels (d) and EKG (c) after application of KCl to the epicardium. Symbols same as in Fig. 1.

The application of a sponge soaked in KCl to the epicardium produced an increase in arterial pressure and a motor response in the animal, especially during the first minute; later motion ceased, and the blood pressure fell slightly. Changes in coronary blood flow were varied, depending on the duration of the effect and also the amount and concentration of the solution. When isotonic solution (1.15%) was used a slight increase in blood pressure and coronary flow (Figure 2, a) was observed; the application of a cotton sponge soaked in 2-3 ml of 5% KCl solution led to considerable changes in coronary blood flow. Most often a biphasic reaction (Figure 2, b) was observed—an increase in coronary blood flow during the first minute, then the flow began progressively to fall against a background of still elevated arterial pressure, which indicates the beginning of coronary vessel constriction. EKG changes appeared as ST elevation and then a monophasic curve, the degree and size proportional to the concentration and quantity of solution (Figure 2, c). After removing the sponge and carefully washing the area of pericardium with warm Ringers solution a restoration of all functions studied was observed.

Upon carrying out experiments using perfusion of the coronary arteries it was established that application of a 5% solution of KCl always produces elevation of coronary vessel tone. In this series of experiments it was noted that increase in coronary vessel tone was more marked when the sponge was placed on the perfused region. In Figure 2, d is demonstrated an experiment in which, as usual, perfusion of the circumflex branch of the left coronary artery was performed. When the sponge was placed on the region of the heart which is nourished by the descending branch of the left coronary artery, only slight changes in the tone of the vessels was observed in the area of myocardium which is supplied by the circumflex branch (Figure 2, d, I; at the mark two the sponge was soaked with 5% KCl solution). Placement of the same sponge on that region which is supplied by the perfused artery evoked pronounced and prolonged increase in vascular tone in the given region (Figure 2, d, II). Experiment using perfusion with constant volume revealed that constriction occures after 5-10 sec. This phase is frequently masked in experiments utilizing the thermoelectric method, since in the first minute a considerable increase in blood flow occurs as the result of increase in arterial pressure and only after some decrease in arterial pressure and more marked coronary vessel constriction is the fall in blood flow recorded.

EKG changes after application of 5% KCl solution were the same, the coronary blood flow increasing in the first phase and decreasing in the second phase, and in those experiments in which a decrease in the volume velocity of blood flow was not observed. Similar EKG changes (elevated ST, monophasic curve) as described above were observed after intracoronary injection of KCl, which took place at the fall of coronary vessel tone. Such uniform nature of the EKG changes upon dissimilar changes in coronary blood flow indicates that pathological EKG changes in the given experimental conditions are not related to myocardial ischemica, but, in all probability, are consequences of the depolarizing action of the potassium ion.

Application of concentrated KCl solutions to the epicardium leads to intense irritation of cardiac receptors which may affect not only the blood supply to the heart but also (reflexly via the vasculomotor center) the blood supply of other organs. Thus, when KCl is applied to the epicardium, changes in the volume velocity of blood flow in vessels of the kidneys, liver, intestine, spleen, and skeletal muscle are detected. For vessels of the kidneys, liver, intestine and skeletal muscle the blood flow most characteristically decreases (Figure 2, e) and in the spleen variable changes in vessel tone are observed.

The changes described in other vascular regions, and also the motor reaction of the animal immediately after application of concentrated potassium solutions indicate the reflex nature of the changes upon irritation of cardiac receptors. Section of the vagus nerves and administration of atropine do not abolish the vascular constrictor reaction of the coronary vessels, nor does injection of dihydroergotamine. Referring to the data in the literature, one may hypothesize that the path of this reflex goes through the stellate ganglion. Thus, I. M. Rodionov [3], studying the blood pressure reaction upon stimulating the pericardium with KCl solutions of various concentrations, described three types of reaction: upon weak stimulation—pressor; upon moderate stimulation—depressor; and upon stronger stimulation—again pressor reaction. The third type of reflex, evoked by the instillation of concentrated KCl solutions in the pericardium, according to this author, disappeared only after removal of the stellate ganglion.

From our data obtained in experiments on the intact organism, it follows that the direct action of low concentrations of potassium on the coronary vessels is to dilate them, as decrease in their tone is observed both after injection of KCl into the coronary artery and after its injection into the entire circulatory bed. Stimulation of cardiac receptors by rapidly and deeply penetrating concentrated solutions of potassium leads to reflex constriction of the coronary vessels.

As the control experiments show, after the application of concentrated NaCl solution no increase in coronary vessel tone is observed, although the usual pressor reaction takes place.

CONCLUSION

The influence of potassium on the coronary circulation was studied. Experiments were carried out on dogs under morphine-urethane anesthesia with the use of thermoelectric recording of the coronary circulation volume velocity, and with the resistography method with perfusion through the coronary artery at constant blood volume. Intracoronary and intravenous injections of different doses of potassium chloride caused coronary dilatation. Large doses led to cardiac arrest.

In most of the cases there was a reduction of the cardiac blood supply after application of concentrated potassium chloride solution to the epicardium. However, it increased in rare cases when the blood pressure was greatly elevated, thus compensating a slight rise of the coronary vessel tone. The coronary tone rose to a greater degree at the place of K application than in the remote zone.

In these experiments the EKG changes seen were similar to those observed in myocardial infraction. They did not correlate with changes of coronary circulation.

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