development of postinfarction heart failure and hypertrophy of RV. Consequently, the development of right ventricular hypertrophy depends not only on the size of the infarct, but also on the functional state of the residual left ventricular myocardium.

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ELECTRICAL ACTIVITY OF THE HEART DURING ANTI-ISCHEMIC PROTECTION OF THE MYOCARDIUM

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KEY WORDS: electrical activity of the heart; cardioplegia; ischemia; papaverine

About 50 methods and modifications of cardioplegia have been suggested to protect the myocardium against ischemia during open heart operations [11], for many investigations have shown that prolonged ischemia of the heart without special protection gives rise to irreversible changes in it. The effectiveness of cardioplegia is assessed on the basis of the results of clinical, biochemical, electrophysiological, functional, and morphological investigations [1, 3, 7, 9, 10, 12-15].

The aim of this investigation was to determine to what extent the effectiveness of cardioplegia can be judged from the electrical activity (EA) of the heart, and how its parameters may be analyzed.

EXPERIMENTAL METHOD

Three series of experiments were carried out on 54 mongrel dogs. Animals weighing 4-10 kg served as heart donors, dogs weighing from 18 to 30 kg as perfusion donors. Trimeperidine (7.0 mg/kg), droperidol (0.5 mg/kg), and atropine (0.2 mg/kg) were injected intramuscularly. The operations were performed under intravenous general anesthesia (pentobarbital, 25-30 mg/kg) with artificial ventilation of the lungs.

In series I (nine experiments) a heart-lung preparation was isolated from the heart donor, the ascending aorta was cannulated, and a high-potassium (25 meq/liter) cardioplegic

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solution, cooled beforehand to 15°C, was injected through it. All components of the perfusion fluid used and details of the experimental model were described previously [4, 5]. Injection of the cardioplegic solution led to arrest of the heart, which was then transferred into a vessel containing physiological saline (15°C). Perfusion with cardioplegic solution was repeated every 20 min. The heart was preserved in this way for 120 min. During this time the lungs were removed, the pulmonary artery and auricle of the left atrium were cannulated, and the heart was prepared for reperfusion with a donor's blood: through the ascending aorta initially, and 15 min later through the left atrium, with the working left ventricle for 60 min.

In series II (nine experiments) the same method was used; the only difference was that papaverine (20 mg/liter) was added to the perfusion fluid. In the control series (nine experiments), immediately after isolation of the heart-lung preparation, a switch was made to a system of perfusion of the heart from a donor, after which the lungs were removed, i.e., the cardioplegic arrest and ischemia of the isolated heart were excluded.

EA of the heart was recorded on an eight-channel Mingograf-800 instrument (Elema Schonander), by means of bipolar electrodes fixed in the region of the right atrium and the apex of the heart. EA was analyzed from the time of isolation of the stabilized heart-lung preparation until the end of the 60th minute of reperfusion. The following parameters were assessed: from the atrial ECG (AECG) – the frequency of atrial contractions, the index of atrial arrhythmia, and the duration and amplitude of the P wave; from the ventricular ECG (VECG) – the frequency of ventricular contractions, the index of ventricular arrhythmia, the duration of the QRS complex and QT interval, and the amplitude of the R wave and QRS complex. The duration of atrioventricular (A–V) conduction was measured between the origin of the P wave on the AECG and the origin of the Q (R) wave on the VECG.

EXPERIMENTAL RESULTS

In the control series the parameters of EA of the isolated heart remained virtually unchanged throughout the period of observation. The results of the experimental series were compared with them.

In the experiments of series I injection of the cardioplegic solution caused varied changes in EA of the heart. In three experiments normal A–V conduction was preserved until atrial or ventricular arrest. Conversely, in six cases dissociation took place between the work of the atria and of the ventricles according to the incomplete, and later complete, A–V block. In four of them, contractions of the atria and ventricles remained coordinated until cardiac arrest, with preservation of the shape of the AECG and VECG, but in two cases, ventricular fibrillation was recorded before cardiac arrest. Initial cardioplegic perfusion caused atrial arrest after 57.0 ± 16.9 sec and ventricular arrest after 49.5 ± 13.7 sec; complete cardiac arrest occurred after 63.8 ± 15.7 sec. During restorative reperfusion with a donor's blood, resumption of atrial and ventricular EA in each experiment took place, not simultaneously, but with a considerable temporal scatter – from 2 to 257 sec. However, the mean time of appearance of atrial and ventricular activity was the same; 84.2 ± 39.0 sec for atrial (scatter 2-257 sec), and 84.7 ± 48.2 sec for ventricular (scatter 2-240 sec).

In each experiment the time of atrial and ventricular arrest was compared with the time of recovery of EA in these same parts of the heart during reperfusion. Definite correlation was observed between the parameters examined: in that part of the heart where arrest had occurred previously, EA recovered more rapidly. In the great majority of cases the restored EA reflected atrial and ventricular fibrillation. Spontaneous defibrillation of the heart was never once observed.

After reperfusion for 10 min with warm blood electrical defibrillation was carried out by a 500 V condenser discharge, which restored coordinated contractions of atria and ventricles. However, the character of electrical activity in these cases was not uniform. In five cases a complete A–V block was recorded, to be followed by sinus rhythm. In four cases sinus rhythm was restored immediately after electrical defibrillation, with a tendency toward slowing of A–V conduction.

Comparison of EA parameters obtained during the subsequent 60-min period of reperfusion with the results of the control series showed that the location of the pacemaker, the heart rate, and the indices of atrial and ventricular arrhythmia were virtually identical. This is evidence that the form of cardioplegia used provides anti-ischemic protection of the car-

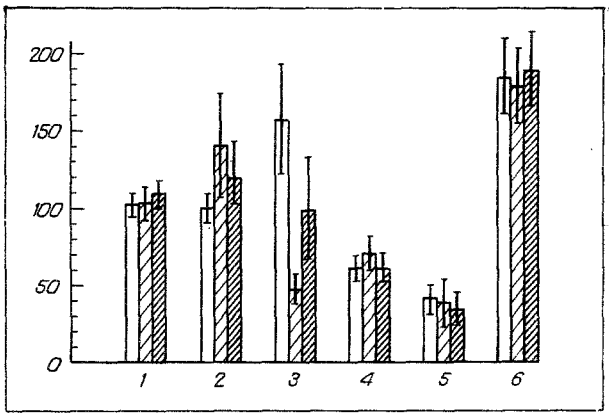

Fig. 1. Supraventricular and ventricular cardiac EA at 60th minute of reperfusion after cardioplegia. Unshaded columns, control series; columns with widely spaced shading – series I (cardioplegia without papaverine); columns with close shading – series II (cardioplegia with addition of papaverine to perfusion solution). 1) Heart rate (beats/min, scale 1:1); 2) duration of PQ interval (in sec, scale 1000:1); 3) amplitude of P wave (in mm, scale 1000:1); 4) duration of QRS interval (in sec, scale 1000:1); 5) duration of Q–T interval (in sec, scale 100:1); 6) amplitude of QRS complex (in mm, scale 1000:1).

diac pacemakers. Parameters characterizing the state of the ventricles, although differing a little, did not in most cases do so significantly. The greatest differences were observed in values characterizing the state of the atria and of A–V conduction. The amplitude of the P wave in this series, starting with the 30th minute of reperfusion, was significantly lower than in the control. The duration of the P wave and of the PQ interval also were constantly greater than in the control (Fig. 1), i.e., changes arising in the atria and in the region of the A–V node during ischemia were not completely restored during reperfusion.

This suggested that the reason for the incomplete protection of the heart was the inadequate supply of cardioplegic perfusion fluid to the region of the atria and the atrial septum. This suggestion was based on investigations showing that a high-potassium solution induces spasm of the coronary arteries and an increase in vascular resistance [6, 8]. To eliminate these undesirable effects, papaverine, a drug which lowers smooth muscle tone [2], and which ought therefore to lead to the more rapid and complete flow of cardioplegic solution into the supraventricular parts, was added to the cardioplegic perfusion fluid in series II.

The results of series II in fact were substantially better. Cardiac arrest occurred sooner (atrial by 48.7 ± 14.3 sec, ventricular by 44.7 ± 16.8 sec, complete arrest by 52.9 ± 13.4 sec); fibrillation of any part of the heart never developed, and in all experiments spontaneous recovery of sinus rhythm was observed followed by gradual normalization of the duration of A–V conduction (from 0.32–0.24 to 0.15 sec). By the 15th minute of reperfusion, parameters of cardiac EA returned to their initial values before cardioplegia, which did not differ from those in the control and remained stable throughout the 60 min of reperfusion. The conduction disturbances disappeared much faster in ths series than in experimental series I; the reduction in amplitude of the P wave, which occurred previously, likewise was not observed (Fig. 1).

The experimental results showed that by recording EA of the ventricles and EA of the supraventricular portions of the heart separately, a sufficiently complete indication of the adequacy of cardioplegia can be obtained. The separate electrophysiological analysis of the different heart structures is essential, because the cardioplegic effect may differ for different parts of the heart, as occurred in series I of these experiments. This difference can be abolished by improving the perfusion of the cardioplegic solution with the aid of papaverine, as the experiments of series II demonstrated.

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ROLE OF LEUKOCYTES IN HEMATOVASAL REGULATION OF THE CIRCULATION

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The blood cells have been shown to play a direct role in the intimate mechanisms regulating the regional circulation of the blood and, in particular, in the pathogenesis of its disturbances [2]. On the basis of research in this field the hypothesis of hematovasal regulation of the regional circulation has been proposed, according to which changes taking place in it are the result of combined changes in the state of the vascular network and of the blood flowing along it; these changes, moreover, may be interdependent. The role of platelets and erythrocytes has been relatively well studied in this context, but that of leukocytes has received far less study. Yet is was suggested a long time ago that leukocytes may influence the circulation of the blood not only mechanically, but also through biochemical action on elements of the blood – vessel wall system [3]. This possibility appears even more probable after discovery of synthesis of a platelet activating factor [5], of vasoactive metabolites of arachidonic acid [6], and of several highly active protein regulators [9] in leukocytes. As yet, however, the concrete role of leukocytes in regulation of the functional state of the vascular network and blood cells, especially platelets, has not yet been explained.

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