METHODS

Feasibility of Myocardial pH-Monitoring during Heart Surgery under Conditions of Cardioplegic Ischemia

L. A. Bokeriya, R. R. Movsesyan, G. A. Bledzhyants, T. B. Averina, and A. S. Nikiforov

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The first results of the use of pH-monitoring of the myocardium with a Khuri monitor (Terumo Cardiovascular Systems Corporation) are presented. Before aorta clamping, the pH changes depended on the initial degree of damage to the examined myocardial segment. pH-Monitoring enabled urgent modification of the cardioplegia protocol, which helped to normalize pH and to prevent severe postoperative complications. The thermometric and pH-metric data were compared with the results of clinical and morphological studies. pH-monitoring made it possible to control myocardial vitality during the surgical intervention.

Key Words: *myocardial pH-monitoring; cardioplegia; artificial circulation; assessment of myocardial revascularization*

The search for efficient methods of organism protection and evaluation of the genesis of damage to organs during surgical intervention under conditions of artificial circulation remains an actual problem of cardiovascular surgery. Unfortunately, there is no reliable diagnostic method, which would provide on-line monitoring of the myocardial metabolism during cardioplegic ischemia. Modern cardiac surgery uses such methods as evaluation of electromechanical work of the heart according to ECG and echocardiography data, assessment of patient's status including the demand of inotropic drugs, essay of biochemical factors of damage (lactate, myoglobin, troponin, *etc*.), and morphological analysis of biopsy specimens [1-3].

A. N. Bakulev Research Center of Cardiovascular Surgery, Russian Academy of Medical Sciences, Moscow. ***Address for correspondence:*** movses@bk.ru. R. R. Movsesyan

On the basis of experimental and clinical data of pH-monitoring in various tissues, a new device was introduced into medical practice for on-line diagnosis of tissue metabolism [5,6]. Until now no method except for pH-monitoring is available for on-line assessment of myocardial metabolism during cardioplegic ischemia and reperfusion. The pH-monitor allows evaluation of the results of cardioplegic protection and express diagnosis of the efficiency of myocardial revascularization [8]. We carried out a complex study of the state of the myocardium during surgery with on-line pH-monitoring of the myocardium.

MATERIALS AND METHODS

A pH-cardiomonitor Khuri (Terumo Cardiovascular Systems Corporation) was used during open-heart surgery in patients with ischemic heart disease (IHD,

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n=10). The device consisted of two basic units: a monitor with recording unit and a set of disposable electrodes (two myocardial pH-electrodes, one direct reference electrode connected to pH-meter module with a cable, and an L-type myocardial pH electrode). Two myocardial pH-electrodes were sealed-off tubes made of pH-sensitive glass and filled with electrolyte solution where the Ag/AgCl wire electrode was situated. The upper part of the myocardial pH-electrode contained a thermistor for measuring heart temperature. The barrel of the electrode was made of polypropylene. The reference electrode consisted of silver wire in a plastic tube filled with KCl solution.

pH-monitoring was performed during coronary artery bypass surgery in various basins of the coronary arteries. Three to six bypasses were made in each patients according to the method accepted in A. N. Bakulev Research Center of Cardiovascular Surgery. The operations were carried out under conditions of artificial circulation, hypothermic perfusion, and cardioplegic protection of the myocardium with blood-based Buckberg solution (Köhler Chemie, *n*=3) or Bretschneider solution (Custodiol, *n*=7). The mean durations of artificial circulation and aorta clamping were 145 and 85 min, correspondingly.

Intraoperative protection of the myocardium was performed according to certified protocols. Single antegrade infusion of Custodiol solution (2000 ml, Köhler Chemie) was performed at 4-10°C for 8 min under a pressure of 50-60 mm Hg in the aorta root. Buckberg solution was administered both in antegrade and retrograde directions via a heat exchanger (induction, reinfusion at 4-8°C, and the controlled reperfusion at 37°C) with the perfusate (1:4 ratio) at a rate of 200-300 ml/min for 2-4 min. Various cardioplegic solutions were used for induction, reinfusion, and controlled reperfusion after Buckberg. The intraoperative protection of the myocardium included drainage of the left cardiac cavities and external cooling of the pericardial cavity according to the methods of open-heart surgery accepted in A. N. Bakulev Research Center of Cardiovascular Surgery.

After the onset of artificial circulation, Khuri electrodes were mounted. The myocardial pH-electrodes were fixed in the thickness of the left and right ventricular myocardium in vessel-free area. The glass body of the electrode was fixed within the myocardium with a single suture. The position and size of the glass electrode were chosen to minimize the risk of endocardium perforation. The reference electrode was implanted into the subcutaneous fat on the thorax.

The research protocol included the data on myocardial pH-metry and thermometry (*n*=10) throughout the period of cardioplegic ischemia. These data were compared with the results of clinical examintions (electrical activity of the heart, pumping and contractile function, and dependence on inotropic support), biochemical tests (coronary sinus lactate), and morphological study (biopsy in 3 cases).

RESULTS

All cases were characterized by uneventful clinical course of postoperative period, which corresponded to the severity and volume of surgery. There was no clinical mortality. The mean duration of stay in intensive care unit was 3 days.

According to the examination protocols (Khuri, Terumo Cardiovascular Systems Corporation), the critical level of myocardial pH was chosen as 6.0 [4-6]. Temperature and pH of the myocardium were recorded from the moment of electrode mounting before cannulation of the major vessels. Before aorta clamping, pH values varied from 6.8 to 7.3, which probably depended on the initial severity of lesion in the examined myocardial segment. After aorta clamping and the onset of cardioplegic infusion, a drastic temperature drop was observed in the external subdivisions of the myocardium of the left and right ventricles (Fig. 1). The additional shifts of the temperature curve coincided with the moment of external cooling. At the start of this cooling, the myocardial temperature decreased to minimal values of 5-8°C (Fig. 1-2).

The shift of myocardial pH towards the mean pH of the cardioplegic solution was documented immediately after the onset of infusion (Fig. 1). In 9 cases, pH did not drop below the threshold level of 6.0 during the entire period of cardioplegic ischemia (Fig. 1). Periods of warming and reperfusion were clearly seen. In all patients uniform recovery of myocardial pH to the physiological level was noted (Fig. 1).

In one case, a non-uniform temperature drop combined with a persistent pH decrease below critical level (pH 5.95) was observed immediately after the start of cardioplegic infusion. Probably, these events resulted from some obstacle to perfusion such as critically narrowed segment of the left coronary artery. In this case, repeated cardioplegia was immediately started via the coronary sinus, which rapidly normalized myocardial pH to the value recorded in the right ventricular myocardium by the second electrode (Fig. 2). The interval between both cardioplegic sessions was 5 min, and the total time of the cardioplegic ischemia was 92 min. In this patient, bypass in three coronary arteries and needle-type biopsy in the left and right ventricles were

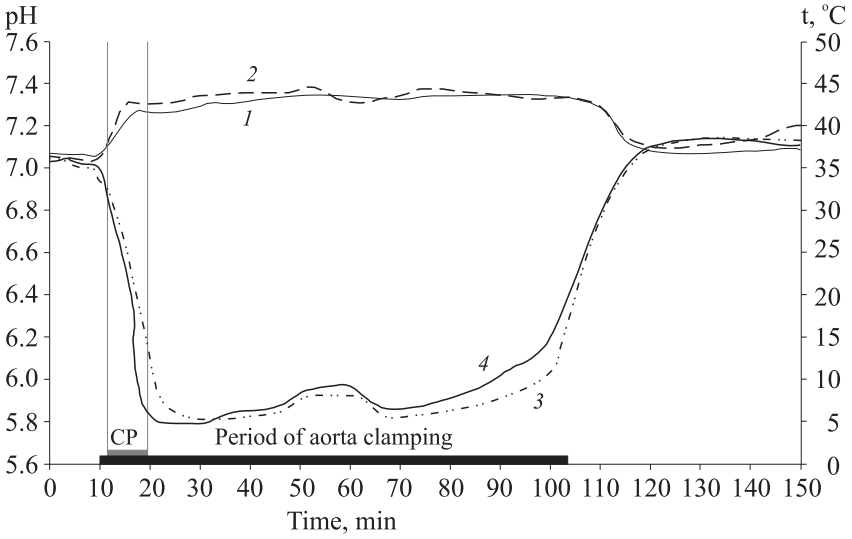

Fig. 1. Kinetics of pH- and thermometry data during the cardioplegic ischemia with Custodiol solution in the "normal" myocardium without perfusion obstacles. Here and in Fig. 2: *1*) pH in the left ventricle; *2*) pH in the right ventricle; *3*) temperature in the left ventricle; *4*) temperature in the right ventricle. CP, cardioplegia.

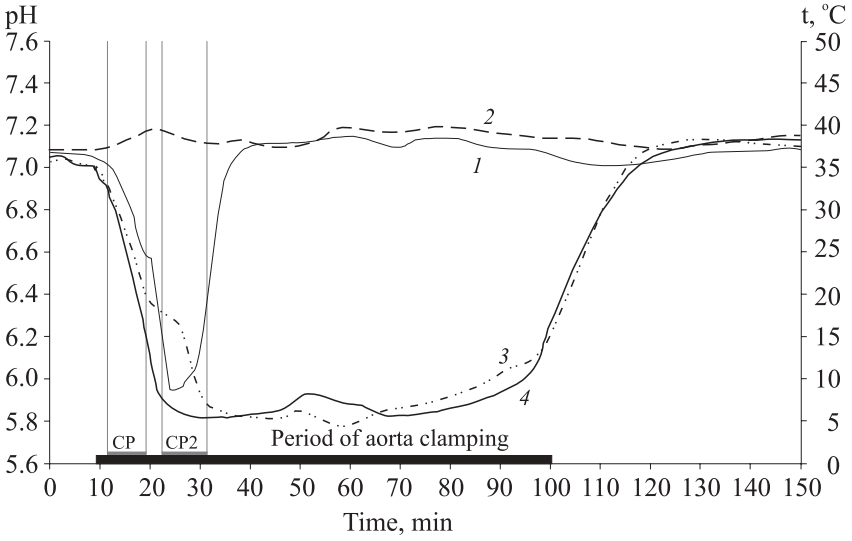

Fig. 2. A drastic drop in myocardial pH due to disturbance in the supply of cardioplegic Custodiol solution to the basin of the left coronary artery. CP2 marks the period of repeated cardioplegic infusion.

performed. There was no further pH drop. The reperfusion data corresponded to physiological norm.

Manifestations of acute cardiac insufficiency in the early postoperative period were observed in two patients (Custodiol subgroup). In addition to coronary artery bypass, geometrical reconstruction of the left ventricle after resection of aneurysmatic expanded area of the damaged myocardium was performed in these patients. In these cases, a short-term intraaortal balloon contrapulsation was performed in the early postoperative period.

Four patients with initially pronounced dilation of the cardiac cavities (Custodiol, n=3; Buckberg, n=1) demonstrated moderate decrease of contractile and pumping function of the heart in the early postoperative period (ejection fraction in the left ventricle <40%).

In 3 cases (Custodiol), cardiac activity was restored after single defibrillation, and in one case (Buckberg) after multiple defibrillation. All patients received inotropic therapy with dopamine and dobutamine.

Infusion of epinephrine in therapeutic doses (up to 0.05 mg/kg/min) was performed in 50% cases (3 cases with Custodiol and 2 cases with Buckberg solutions). The level of lactate measured in the coronary sinus never surpassed the lactate level in the peripheral blood. In all tree cases, morphological examination of biopsy specimens from the myocardium of the left and right ventricles revealed no significant changes in the structure of cardiomyocytes.

Biochemical analyses and clinical observations during the postoperative period revealed no significant differences. No clear-cut morphological signs of severe damage to the myocardium were observed during cardioplegic ischemia. Probably, the possible severe postoperative complications were

prevented by proper operative measures needed in the single case with inadequate cardioplegia.

This study showed that on-line thermo- and pH-metry of the myocardium adequately evaluate the state of the heart. Using these methods, the surgeons can control the functional state of the myocardium during the period of cardioplegic ischemia.

An imperfection of the tested Khuri monitor is excessive length of the disposable electrodes, which prevents their application in cases with myocardium thickness less than 0.7 cm.

Analysis of the data obtained before and after the surgical correction suggests that the described method can be used to assess the efficiency of myocardial revascularization.

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