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Parameters of Ionic and Acid-Base Balance during Assist Circulation with a LVAD Disc Pump

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In chronic experiments on calves, the effect of the left-ventricular assist device (LVAD) technique by using a disc pump on the indicators of ionic and acid-base homeostasis. At blood velocity of 20% from the total volume, a trend towards an increase in K^+ concentration and a slight decrease in the concentration of Na^+, pH, and standard base excess in animal plasma were observed. If the blood velocity increased up to 90%, the indicators of ionic and acid-base homeostasis returned to their baseline values. In parallel, stroke volume and cardiac output as well as BP at the outlet of the heart and inside it and HR increased simultaneously with a blood pressure decrease in the input cannula site. There were no differences in plasma concentrations of Ca^{2+} and Cl^- at different blood flow volumes.

Key Words: *assist circulation; disc pump; ionic homeostasis; acid-base balance; plasma*

Acid-base and electrolyte homeostasis disorders are one of all distinguishing characteristics of congestive heart failure [10]. In ischemia, myocytes lose their ability to maintain normal ionic gradients, resulting in the shift of intracellular potassium (K^+) and calcium (Ca^{2+}) into the extracellular space and the backflow of sodium (Na^+) from the extracellular to the intracellular space. In parallel, there is a decrease in pH and an increase in heart function due to HR elevation [9].

Over the last years, there has been more and more data on the use of left-ventricular assist circulation technique, which is an alternative to heart transplantation. However, this method can cause rapid electrolyte shifts, which in turn can cause changes in electrochemical gradients in tissues and lead to arrhythmogenic vulnerability of the heart [9].

The effects of left-ventricular assist circulation techniques on ionic and acid-base homeostasis are poorly studied. We found only few papers on ion exchange under conditions of assist circulation [5,7,8] and no reports on acid-base equilibrium under these conditions. In light of this, the study of the parameters of ionic and acid-base homeostasis when using assist circulation devices on the example of a certain design is of academic interest. For our study we choose a left-ventricular assist circulation device (LVAD) with a disc pump.

Our aim was to study the effect of LVAD with a disc pump on some parameters of ionic and acid-base homeostasis.

MATERIALS AND METHODS

The experiments were performed on 3 healthy male calves of black-and-white breed (mean age 4 months; body weight 90 kg) without left-ventricular insufficiency. The duration of the first experiment was 9 days. The duration of the second and third experiments was 11 days. All the procedures involving animals were done in accordance with the European Convention for the Protection of Vertebrate Animals Used for Experiments or for Other Scientific Purposes (Strasbourg, 1986) and were approved by the Ethics Committee of the E. N. Meshalkin National Medical Research Center, Ministry of Health of the Russian Federation.

Preparation for the experiment. After fixing the animal on the operating table, a pulse oximeter sensor

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was fastened to the tail, sensors for ECG recording were positioned on the chest, and a silent coagulator electrode was placed on the back. Then, the tracheal intubation was performed a 9-mm endotracheal tube that was fixed to the upper jaw and connected to the breathing circuit of the anesthesia machine for providing artificial lung ventilation; a temperature sensor was installed in the right nasal passage. Philips IntelliVue MP70 Patient Monitor was used to record vital activity (HR, BP, throat temperature, ECG, and blood oxygen saturation). A Venflon catheter was inserted into the lateral auricular vein. Mandatory ventilation was carried out with an oxygen-air (50:50) mixture with sevoflurane content of 4-5 vol.%. Assisted ventilation was performed with 100% oxygen with a similar sevoflurane content until 100% blood oxygen saturation was achieved. The anastomosis between a 12-mm dacron vascular prosthesis and the descending thoracic aorta was formed with a 5/0 thread, suturing the left ventricle, installing a cannula, and removing two flow pathways to connect to the pump. A paracorporeal connection of the disc pump [2,3] was carried out according to the scheme "left ventricular apex—descending portion of the thoracic artery". The supply line was connected to the input cannula, and the outflow line was connected to the outlet pipe.

At the stage of a disc pump connection, blood flow in the volume of 20% of the total one was provided at a speed of 900 rpm. As the rotor speed of the pump increased, the blood flow volume increased to 60% at 1900 rpm and at least 90% of the blood flow at 2400 rpm.

The first blood sampling in animals was done before the pump was connected. Subsequently, blood sampling was performed hourly during the first day and once a day starting from the second day. The blood tests were performed at the E. N. Meshalkin National Medical Research Center; a RADIOMETR ABL800 FLEX blood gas analyzer was used.

Statistical data processing was performed using MatLab software. For each indicator, the mean value over the entire observation period and its error were calculated. The significance of differences between the groups was evaluated using the Student's *t* test at $p<0.05$.

RESULTS

At the stage of disc pump connection at a blood flow rate of 20% of the total volume, there was a clear tendency to elevation of K^+ concentration in the plasma with a simultaneous slight decline in Na^+ concentration. However, as the blood flow volume increased to 90%, these shifts became less pronounced and the ionic homeostasis indicators returned to the baseline values. The concentrations of Ca^{2+} and Cl^- practically did not differ at different blood flow volumes (Table 1).

A similar study [9] has shown that connection of the assist circulation pump (the design and type are not specified) to the heart of animals (sheep) that did not suffer from left ventricular insufficiency was not followed by substantial changes in electrolyte content in the myocardium, these parameters remained within the normal limits. Sheep with left ventricular insufficiency had substantial shifts in electrolyte concentrations. After pump connection to the heart, the parameters of electrolyte balance improved, which, according to the authors, is the result of left ventricular unloading [9].

It can be supposed that in our study, the conditions of short-term cardiac insufficiency were simulated at low blood flow volume (20%). The return of the ion concentration indicators to the baseline values with a blood flow of at least 90% shows that the LVAD technique with the use of a disc pump does not affect ion homeostasis parameters.

At the stage of 20% blood flow volume, a reduction in pH was observed (Table 2), but this parameter remained within the homeostatic range. It has been demonstrated that this is a compensatory mechanism allowing cells to accumulate hydrogen ions, thereby avoiding major changes of pH in the extracellular

TABLE 1. Ionic Homeostasis Parameters at Different Rotational Speeds of the Disc Pump Rotor (rpm) and Blood Flow Volume (in % of the norm) (n=3; $M±m$)

Ion concentration in the plasma, mmol/liter	Before connecting LVAD	After connecting LVAD at the rotor speed and blood flow volume			Normal range, mmol/liter [7]
		900 rpm, at least 20%	1900 rpm, at least 60%	2400 rpm, at least 90%	
K^+	3.7±1.0	4.2±1.0	3.7±0.9	3.8±0.8	3.5-5.2
Na^+	140.9±1.3	139.8±1.2	140.2±1.2	140.7±1.1	135-146
Ca^{2+}	1.19±0.04	1.20±0.1	1.21±0.1	1.21±0.02	1.15-1.27
Cl^-	105.0±0.8	104.5±1.1	104.3±1.1	104.7±1.0	98-106

Note. Here and in Tables 2 and 3: *all indicators are presented as mean values for the entire measurement period (9-11 days).

TABLE 2. Acid—Base Balance Parameters at Different Rotational Speeds of the Disc Pump Rotor (rpm) and Blood Flow Volume (in % of normal range) (n=3; $M\pm m$)

Parameter	Before connecting LVAD	After connecting LVAD at the rotor speed and blood flow volume			Normal range, mmol/liter [7]
		900 rpm, at least 20%	1900 rpm, at least 60%	2400 rpm, at least 90%	
pH	7.43±0.01	7.35±0.03	7.40±0.03	7.40±0.03	7.35-7.45
HCO_3^-, mmol/liter	25.97±0.93	25.42±0.93	25.37±0.88	25.19±0.89	21.2-28.7
Standard base excess cBase(Ecf), mmol/liter	0.35±0.29	-0.47±0.52	-0.20±0.43	-0.20±0.42	-4-2
Anion gap (AG), mmol/liter	13.73±0.87	14.15±0.98	14.44±0.89	14.60±0.90	10-20

TABLE 3. Hemodynamic Parameters at Different Rotational Speeds of the Disc Pump Rotor LVAD (n=3; $M\pm m$)

Disk pump rotor speed, rpm	Systolic volume, ml/m²	Cardiac output, ml/min	Pressure in the input cannula, mm Hg	Pressure in the outlet pipe, mm Hg	Invasive BP, mm Hg	HR, bpm
900	27.33±1.03	2136±156.55	-8±-0.34	76±1.38	83/58±1.38/1.72	78±2.76
1900	40±3.10	3438±358.90	-10±-0.69	110±1.72	92/60±1.72/1.38	85±2.07
2400	52±1.72	5045±202.76	-13±-0.69	134±1.38	100/70±2.76/3.10	97±0.69

Note. After increased rotor speed of the disc pump all the indicators are considerably different from the previous values.

fluid [6]. Since pH is an integral indicator of acid—base equilibrium, it was essential to evaluate some of the buffer components affecting it.

The traditional approach to the acid—base state evaluation of peripheral blood is based on assessment of bicarbonate concentration, standard base excess (cBase(Ecf)), and anion gap. Normally, cBase(Ecf) in humans should be zero [1]. However, cBase(Ecf) indicators in animals can considerably differ from those in humans and, as was proved in the study [4], depend on animal age. It was determined that some cattle animals under 1 year have low cBase(Ecf)= 5.33 mmol/liter, but as the animal grows, this indicator increases and can vary in the range from -1.09 to -1.04 mmol/liter [4].

The standard excess of cBase(Ecf) was calculated by the equation:

$$cBase(Ecf)=C[HCO^-_3]-24.8+16.2x,$$

where x is pH 7.4.

The mean initial cBase(Ecf) was 0.35 mmol/liter. After connection of the disc pump with a developed blood flow of at least 20%, the mean cBase(Ecf) was -0.47 mmol/liter. If the blood flow increased up to 60%, the cBase(Ecf) increased to -0.2 mmol/liter.

In our study, calves under 1 year were used, and accordingly, cBase(Ecf) in the range from 0.35 to -0.47 mmol/liter for these conditions can be considered as normal.

The measured values of the anion gap (AG) were within the normal range. An uptrend of AG in the dynamics of 10-day follow-up could be due to small fluctuations of the plasma concentration of basic ions within their normal range.

To determine the role of hemodynamic factors at different speeds of LVAD disc pump, the main blood circulation parameters were evaluated (Table 3). It was found that as the speed of a disc pump rotor increased, the stroke and cardiac volume grew, respectively, as well as HR, and BP at the outlet of the heart and inside it, while the pressure in the input cannula site decreased. Changes in hemodynamic parameters and the volume of the blood pumped at higher pump speed are likely due to the fact that the pump was operating in parallel with a normally functioning heart in a healthy animal. Thus, the described hemodynamic shifts were directly proportional to the rotor speed.

The obtained findings are the basis for further analysis of homeostasis under the conditions of ventricular failure.

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