

New Type of Pulsatile Flow System for Artificial Heart-Lung Bypass

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ABSTRACT

In the artificial system of heart-lung bypass, used during a surgery on stopped heart, a common problem-causing device is a roller pump. Inexpensive, simple, yet dependable device is in the process of development, with characteristics maximally approximated to the physiological parameters of the organism's natural heart. Substituting for the roller pumps, this device consists of two reservoirs. Hermetic reservoirs are interconnected in parallel. They also connect to other parts of the system with blood tubing. A pneumo consol for artificial ventricles represents the control system and ensures pulsatile blood flow in the biomodel's

KEYWORDS: artificial heart-lung bypass, reservoir, perfusion system

Traditional method of artificial heart-lung bypass (AHLB) during cardiac surgery employs roller pumps in the artificial circulation systems. Because such pumps create non-physiological blood flow in the arterial system, the homeostasis of the body is subjected to a number of negative effects [5]. In order to avoid these effects, frequent control, as well as corrections by medications is needed during the perfusion and post-perfusion periods [2]. In the perfusion system developed in our laboratory [Sakpatenti P2467], ventricular assisting device (VAD) is used as a main pumping module, which is a rather technologically sophisticated and expensive gadget [3,4]. For this reason, even though the device generates the maximum physiological blood flow in the arterial system, it has not found usage in AHLB systems at present.

We set as our goal the development of a relatively inexpensive, simple and reliable pulsatile flow pump in the heart-lung bypass device to ensure maximum physiological blood flow in the arterial system.

MATERIAL AND METHODS

In our own construction of artificial heart-lung bypass system (Fig.1), for performing the function of a pumping device, instead of VAD we used two standard cardiotomy (arterial) reservoirs of hermetic type, fixed at the same level under the oxygenator. They each had the capacity of 1500 ml. Y-shaped connectors and blood tubes connect inlet ports of reservoirs to each other and to the outlet port of the oxygenator. The outlet ports of reservoirs are connected to each other and to the arterial filter with similar connectors and tubes. During the operation of the device, mobilized venous blood was gravitationally flowing from the right chamber of biomodels heart into the venous reservoir. From this reservoir, the rolling pump supplied blood in the oxygenator, located 40 cm above the operating table. From here, the arterial blood flowed and accumulated in one of the arterial reservoirs with closed outlet port, located beneath the oxygenator. After the first reservoir filled up, its inlet port closed and the arterial blood continued to flow into the second reservoir. At this time, the outlet port of the first reservoir opened and blood flowed through arterial filter to aorta. The pressure of the blood supply was maintained by pneumo-impulse control system of VAD, which created pulsatile flow in aorta.

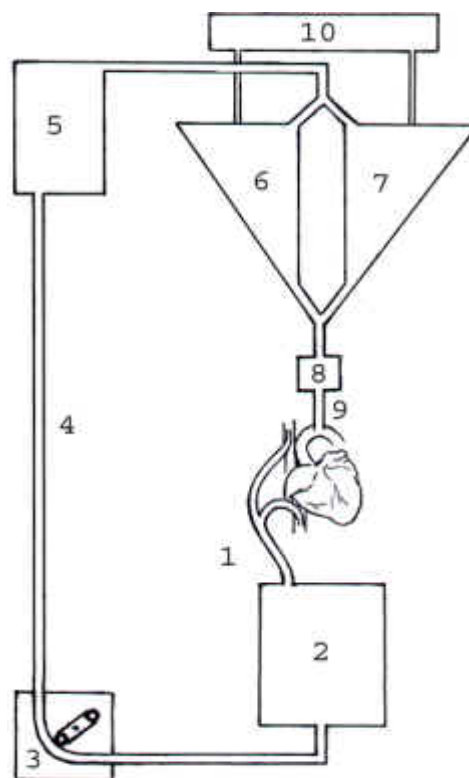


Fig.1 Pulsatile blood flow system for AHLB

1. Vena cava superior and inferior canulas;
2. Venous reservoir;
3. Roller pump;
4. Blood tubing;
5. Oxygenator;
6. First arterial reservoir;
7. Second arterial reservoir;
8. Arterial filter;
9. Aortic canula;
10. Driving system

Experimental studies (total of 12) were carried out on mongrel dogs of both sexes. Under endotracheal narcosis, we carried out sternotomy, pericardiectomy, and the mobilization of the heart and its capital vessels. The canulas were chosen according to the animal's weight and placed into vena cava superior and inferior, and into aorta. Y-type connectors connected vena cava canulas to the inlet port of the venous reservoir, and the outlet port of arterial filter to the aorta canula. We began parallel circulation around the heart and lungs. Using a Swedish-made polygraph "Mingograf-82" we monitored the

electrogram, systemic arterial and venous tension (on femoral vessels of the lower limb) and left arterial pressure (with a special transmural micro catheter). We measured blood flow in the outlet port of arterial filter and on the femoral artery with a flow meter "Nihon Kohden" - Japan [1].

RESULTS

Every test was non-sterile. The experiments were divided into three groups, by the time length of AHLB (Short duration - 30 min.; medium duration - 120 min.; and long duration - 300 min.). In each experiment, we distinguished three stages: before cardioplegia - period of parallel perfusion while the heart is stopped - cardioplegia period; and after the heart function resumption - the reperfusion period. *Tab.1* presents the dynamics of systemic and left atrial tension by duration and the experimental stage. *Tab.2* represents the indicators of output for the same period in the outlet port of the artificial system and on the arteria femoralis.

The duration of parallel perfusion was 10 min. The duration of a single, crystalloid, hypothermic cardioplegia did not exceed 20 min. For the remaining period of each experiment we carried out postcardioplegic reperfusion. Therefore, this reperfusion in the first group lasted for 5 min., in the second group for 85 min. and in the third group for 275 min. This time, synchro-pulsation according to the cardiogram was not among our goals. The pulsating frequency of artificial pumps was 60-80 beats per minute. The systolic volume was adjusted according to the animal's weight, in 35 ml to 55 ml range. *Tab.3* represents the occurrences of heart function resumption in the reperfusion period, by groups. In the first group, a spontaneous (i.e. on its own) resumption of heart's adequate functioning was observed in four cases; in the second group - in one case (in two cases defibrillation was required, in one - the heart function did not resume); in the third group natural resumption occurred twice, and defibrillation was required twice.

Group and AHLB duration	Experimental stages	Tension in art. femoralis (mm Hg)		Tension in left atrium (mm Hg)
		Systolic	Diastolic	
I (30 min)	I – parallel perf.	150	95	8
	II – cardioplegia	135	80	0
	III – reperfusion	140	85	10
II (120 min)	I – parallel perf.	140	90	12
	II – cardioplegia	110	55	0
	III – reperfusion	115	60	15
III (300 min)	I – parallel perf.	130	75	7
	II – cardioplegia	125	65	2
	III – reperfusion	100	40	9

Tab.1 The dynamics of systemic and left atrial tension by experimental stages.

Group and AHLB duration	Experimental stages	Artificial system output (ml/min)	Blood flow in art. femoralis (ml/min)
I (30 min)	I – parallel perf.	800	55
	II - cardioplegia	1350	60
	III - reperfusion	1000	50
II (120 min)	I – parallel perf.	750	65
	II - cardioplegia	1400	65
	III - reperfusion	900	40
III (300 min)	I – parallel perf.	650	65
	II - cardioplegia	1300	55
	III - reperfusion	950	55

Tab.2 The dynamics of magnetic flowmeter indicators by experimental stages.

Group and AHLB duration	Resumption of heart function during reperfusion	Resumption of heart function as a result of defibrillation	Heart function did not resume	All
I (30 min)	4	0	0	4
II (120 min)	1	2	1	4
III (300 min)	2	2	0	4

Tab.3 Indicators of heart function resumption by durations of the experiment .

DISCUSSION

As the *Tab.1* reveals, at any stage of perfusion, physiological systolic-diastolic gradient was maintained in all three groups. In the body of the biomodel, this gradient maintained maximum closeness to the normal perfusion of tissues and organs. During parallel perfusion period, blood flow shunting caused the left atrial tension to diminish. This created conditions for myocardium rehabilitation, especially while shunting volume exceeded 50%. During cardioplegia period, we did not alter pulsatile frequency and volume. After cross clamping of aorta and sealing of vena cava around the inserted canulas, total AHLB was performed. As *Tab.1* reveals, arterial tension and blood flow was not significantly tested. We started reperfusion after declamping of aorta. At this time, the blood flow of artificial system diminished, while we increased the tension at the expense of increases in each cycle's systolic pressure. The frequency of spontaneous (independent) resumption of

heart function was an indicator of the quality of cardioplegia and reperfusion (*Tab.3*). Hence, spontaneous resumption of heart function was observed during short reperfusion in all four cases of the first group. During the long-lasting reperfusion in the second and third groups, carried out non-synchronously, post-cardioplegic myocardium rehabilitation could not be adequately executed [6,7].

CONCLUSION

As the results reveal, the pulsatile system that we developed creates an adequate perfusion blood flow in the arterial system of the biomodel. This system enables us to control not only the pulsating frequency, but also the volume of each stroke. To attain the maximal physiological blood flow, the necessity of synchronizing the perfusion system with the heart function must be considered.

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Система пульсирующего потока нового типа для искусственного сердечно-легочного обхода

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Р Е З Ю М Е

В системах искусственного сердечно-легочного обхода, используемых при операциях на остановленном сердце, одним из основных травмирующих факторов является роликовый насос, функционирующий в качестве нагнетательного устройства. Разработано дешевое, простое, но надежное насосное устройство, по своим выходным характеристикам приближенное к физиологическим параметрам естественного сердца. Оно заменяет роликовый насос, комплектуется из двух герметичных резервуаров, параллельно соединенных между собой, и с деталями системы собственной конструкции. Система управления представлена пневмоприводом для искусственных желудочков сердца и обеспечивает пульсирующий поток в артериальной системе биомодели.

Ключевые слова: *сердечно-легочный обход, резервуары, перфузионная система*